



## **U.S. FISH AND WILDLIFE SERVICE**

**Arizona Fisheries Resources Office - Flagstaff**

**Recommendations for Research, Monitoring, and Conservation of  
Endangered and Native Fishes in Grand Canyon**

**FINAL REPORT  
October 1, 1997**

565  
ENV-4.00  
G671c  
C.1

# **Recommendations for Research, Monitoring, and Conservation of Endangered and Native Fishes in Grand Canyon**

## **FINAL REPORT**

October 1, 1997

First Draft Report: September 23, 1996

Second Draft Report: January 28, 1997

Third Draft Report: April 18, 1997

Final Draft Report: August 20, 1997

Prepared by

Owen T. Gorman, PhD.

Project Coordinator

U.S. Fish and Wildlife Service  
Arizona Fisheries Resources Office  
Flagstaff, Arizona 86001

for

U.S. Bureau of Reclamation  
Upper Colorado Region  
Salt Lake City, Utah

and

Grand Canyon Monitoring and Research Center  
Flagstaff, Arizona

This document addresses requirements of Interagency Acquisition 1425-6-AA-81-80013, Deliverable 5.a.2., Report on Long-term Monitoring recommendations for endangered aquatic resources in Grand Canyon.

## TABLE OF CONTENTS

PREFACE .....	3
EXECUTIVE SUMMARY .....	5
BACKGROUND .....	8
I. GLEN CANYON DAM BIOLOGICAL OPINION .....	11
Elements of the Reasonable and Prudent Alternative .....	11
Schedule and Coordination of RPA Actions .....	14
Reasonable and Prudent Measures to minimize incidental take .....	14
Conservation Recommendations .....	15
II. GCES PHASE II RESEARCH: SUMMARY OF FINDINGS .....	16
Contracted information acquisition for GCES Phase II .....	16
Summary information gained from GCES Phase II studies .....	17
III. RECOMMENDATIONS for RESEARCH, MONITORING, and MANAGEMENT to ADDRESS ELEMENTS of the GLEN CANYON DAM BIOLOGICAL OPINION .....	22
Recommended Mainstem and Tributary Research and Monitoring .....	22
Recommended Little Colorado River Research and Monitoring .....	27
Recommended Management and Conservation Actions .....	29
IV. RECOMMENDED RESEARCH, MONITORING, and MANAGEMENT and CONSERVATION ACTIONS for the ADAPTIVE MANAGEMENT PROGRAM .....	31
Recommended Research and Monitoring Activities .....	32
Recommended Management and Conservation Actions .....	35
V. The ADAPTIVE MANAGEMENT PROCESS and RECOVERY of LISTED SPECIES .....	38
Development of a Life History Model and Management Plan for Recovery of Humpback Chub in Grand Canyon .....	42
CITED LITERATURE AND REPORTS .....	47
Table 1. Summary of Research, Monitoring, and Management Recommendations .....	41
Figure 1. Recovery of Humpback Chub in Grand Canyon within an Adaptive Management Framework .....	43

## PREFACE

The U.S. Fish and Wildlife Service (FWS) Arizona Fishery Resources Office (Flagstaff FRO) was founded in 1991 by Dr. Owen Gorman to conduct contracted research under the Bureau of Reclamation's (BOR) Glen Canyon Dam Environmental Studies (GCES) Phase II program. The Flagstaff FRO conducted studies of habitat use by the endangered humpback chub and other native fishes in the Little Colorado River (LCR) and other tributaries within Grand Canyon over the period 1991-1995. Following completion of Phase II studies, the Flagstaff FRO assumed a technical support role to BOR for implementation of the Glen Canyon Dam Biological Opinion ("Biological Opinion") and its derivative, the 1996 Biological Conference Opinions on Operation of Glen Canyon Dam-Controlled Release for Habitat and Beach Building. Technical support included assistance in: the development of the 1996 Glen Canyon Dam Beach/Building Flow; conducting workshops for integration of GCES Phase II studies; designing field studies for native and endangered species including endangered fish (humpback chub), birds (southwestern willow flycatcher), and snails (Kanab ambersnail); and conducting field studies evaluating the impact of the experimental flood on endangered and native fishes. Additional work, added through modification of Interagency Agreement 1425-6-AA-81-80013, included assistance in conducting field work, analyzing data and writing reports for studies on endangered Kanab ambersnail and southwestern willow flycatcher, and assisting in geochemical studies in the LCR. Throughout 1996, the Flagstaff FRO represented the Service in the development of the charters for the Grand Canyon Adaptive Management Program (AMP) and the Grand Canyon Monitoring and Research Center (GCMRC), and in the development of the Long-Term Monitoring and Research Plan for the GCMRC.

Through involvement in GCES Phase II and subsequent monitoring programs, the Flagstaff FRO has acquired extensive experience with the history, environment, problems, processes, and biological communities of Grand Canyon. The coupling of this extensive experience with the Service's responsibility for management and protection of endangered species placed the Flagstaff FRO in a unique partnership role to assist the Bureau in addressing elements of the Biological Opinion. In that capacity, the Flagstaff FRO has played a major role in the BOR's GCES program by participating in the development, execution, and synthesis of studies addressing endangered species. As an active partner, the Flagstaff FRO ensured the success and integrity of the BOR's GCES program. As the AMP and GCMRC now assume the role of the GCES program, an active partnership with the Flagstaff FRO will ensure a smooth transition of programs and make certain that endangered species issues continue to be a major focus of management programs in Grand Canyon.

As part of the FY1996-1997 Interagency Acquisition with the BOR, the Flagstaff FRO was asked to draft a report providing recommendations on implementing the Reasonable and Prudent Alternative (RPA) of the Biological Opinion. Recommendations were to be guided by the RPA, Reasonable and Prudent Measures (RPMs), and Conservation Recommendations contained within the Biological Opinion (USFWS 1994). Recommendations were to address present and future needs for research, monitoring, and management and conservation actions. Thus, the principal purpose of the report was to provide guidance to BOR in taking actions that will remove jeopardy to endangered fishes (humpback chub and razorback sucker) in Grand Canyon and secondarily to

provide guidance in research, monitoring and management actions that would assure long-term maintenance of these and other native fish species in Grand Canyon.

The signing of the Record of Decision (ROD) for the Glen Canyon Dam Environmental Impact Statement (EIS) in October 1996 marked the beginning of a new era in which Glen Canyon Dam is to be operated through an adaptive management process for the benefit of the natural resources of Grand and Glen Canyons. The signing of the ROD formally established the AMP and the GCMRC as the principle components of the management process. Thus, the GCMRC replaced the BOR's GCES program and assumed responsibility for BOR's Transition Monitoring contracts, including that with the Flagstaff FRO. Early in 1997, the GCMRC asked the Flagstaff FRO to expand the purpose of the recommendations report to include management of endangered and native species within an ecosystem adaptive management framework. This change was reflected in a modification of the Interagency Agreement for FY1997.

Originally, the recommendations report was to be completed by the end of FY1996. However, the Flagstaff FRO assumed additional work in FY1996 as outlined in a contract modification, and the schedule for the delivery of the report was adjusted. The first draft recommendations report was developed over the summer of 1996 and paralleled development of draft charters of the AMP and GCMRC and the draft long-term monitoring and research plan for the GCMRC. The first draft was distributed on 23 September 1996 to BOR, FWS, and GCMRC. After addressing comments by reviewers, a second draft was distributed on 18 January 1997. The third draft was distributed 18 April 1997 and reflected the suggestions of the GCMRC in regard to changing roles and responsibilities of the BOR, AMP and GCMRC for the management of Grand-Glen Canyon natural resources. The final draft (August 20, 1997) incorporated additional suggestions by the FWS Phoenix Ecological Services Office. David Wegner (BOR), Christine Karas (BOR), Barry Gold (GCMRC), Debra Bills (FWS), Don Metz (FWS), and Stuart Leon (FWS) provided many useful suggestions for improving this report.

Report organization: The Background section provides a review of the Modified Low Fluctuating Flow Alternative (MLFF; "Preferred Alternative") of the of the Glen Canyon Dam EIS. Section I outlines the Glen Canyon Dam Biological Opinion and the jeopardy opinion on the MLFF and actions prescribed in the RPA to adequately address jeopardy to continued existence of humpback chub in Grand Canyon. Section II summarizes the results of GCES Phase II studies and the present understanding of the ecology of endangered species of the Grand Canyon. Section III identifies information gaps and research, monitoring, and management actions needed to address the Glen Canyon Dam Biological Opinion. Section IV presents recommended additional research, monitoring, and management and conservation actions to the AMP for endangered species. Section V outlines a framework for research and monitoring, integration and synthesis, and formulation and implementation of management actions within an adaptive management process.

## EXECUTIVE SUMMARY

The U.S. Fish and Wildlife Service's (FWS, "Service") Arizona Fishery Resources Office in Flagstaff (Flagstaff FRO) was asked by the Bureau of Reclamation (BOR) through Interagency Acquisition 1425-6-AA-81-80013 to provide recommendations for research and monitoring that address the Reasonable and Prudent Alternative (RPA) and Reasonable and Prudent Measures (RPM) of the Glen Canyon Dam Biological Opinion, particularly in regard to native and endangered fishes (humpback chub and razorback sucker). The signing of the Record of Decision (ROD) by the Secretary of the Interior for the Glen Canyon Dam Environmental Impact Statement (EIS) in 1996 established an Adaptive Management Program (AMP) for operating Glen Canyon Dam for the benefit of all natural resources of the Grand Canyon ecosystem. Included in AMP goals are the conservation and management of native and listed fishes. The signing of the ROD formally established the Grand Canyon Monitoring and Research Center (GCMRC) to implement monitoring and research needs for the AMP. The GCMRC requested that the Flagstaff FRO provide recommendations for research and monitoring directed toward conservation and management of native and listed fishes. Prior to presenting recommendations, reviews of the Biological Opinion, Grand Canyon Protection Act, Glen Canyon Dam Environmental Impact Statement, and contracts awarded under Glen Canyon Environmental Studies (GCES) Phase II are provided.

GCES Phase II study reports revealed a large body of information about the distribution, abundance, movement, life history, and ecology of the endangered humpback chub (HBC) and other native fishes of Grand Canyon. However, much of the data has been analyzed in an unintegrated form and therefore lacks a comprehensive perspective, particularly in some areas that are critical to management and recovery of endangered species. Information gaps in GCES Phase II studies and areas in need of integration were identified in this report for future research and analysis. Information not provided by GCES Phase II studies but necessary for implementing the RPA and recommended conservation actions was identified. Based on a review of GCES Phase II studies and assessment of additional information needs, recommendations are provided for research, monitoring, and conservation actions that would guide the BOR and the AMP in the restoration and long-term maintenance of humpback chub (HBC) in Grand Canyon. A capsulization of the report's review of GCES Phase II findings and recommended management and conservation actions and research and monitoring that address the Biological Opinion elements are provided below.

### GCES PHASE II: SUMMARY of FINDINGS

GCES Phase II studies were divided between the mainstem Colorado River and Little Colorado River (LCR) and other tributaries and conducted by many groups of researchers. In the mainstem, HBC were limited to eight discrete populations/aggregations within Grand Canyon, but more than 95% of all HBC were found in the Little Colorado River (LCR) and inflow zone of the Colorado River. Significant spawning did not occur in the mainstem where recruitment and survivorship of juvenile and young-of-year (YOY) HBC were very low. Low survivorship was attributed to low

temperatures and a lack of stable habitats; these environmental conditions were caused by chronic daily fluctuation of cold, hypolimnetic releases from Glen Canyon Dam. Maintenance of HBC in Grand Canyon appeared to be entirely dependent on reproduction in the LCR. Most YOY and juvenile HBC found in the mainstem originated from the LCR and a large portion of the adult mainstem HBC population ascended the LCR in the spring months to spawn. The adult mainstem population was maintained by recruitment of young adults from the LCR. The adult HBC population in the LCR appears to have declined by as much as 50% over the past 15 years and a sharp decline has been observed after 1993. A decline of ~14% in condition of adult HBC captured in the LCR confluence parallels the reduction in population size.

#### RECOMMENDATIONS for RESEARCH, MONITORING, and MANAGEMENT to ADDRESS the ELEMENTS of the GLEN CANYON DAM BIOLOGICAL OPINION

Most recommended research and monitoring is an elaboration of RPA and RPM elements and otherwise addresses information gaps and the lack of integration of GCES Phase II studies. Recommended research includes: studies related to experimental flows and thermal warming; additional mainstem habitat studies linked to LCR and other tributary habitat studies; further study of food resources and productivity tied to fish populations; temperature, growth and survivorship studies for HBC; native and non-native interactions; fish diseases; and additional studies on the environments and native fishes in tributary streams. Special attention was given to linking additional studies in the LCR to experimental flows and thermal warming studies in the mainstem as outlined in the RPA. Recommended management actions include: development of a management plan for razorback sucker and formation of a team of scientists and resource managers to address establishing additional spawning populations of HBC in Grand Canyon.

#### RECOMMENDED RESEARCH, MONITORING, and MANAGEMENT and CONSERVATION ACTIONS for the ADAPTIVE MANAGEMENT PROGRAM

Additional recommendations are provided to guide BOR and the AMP for the long-term maintenance of endangered species in Grand Canyon. There is a critical need to integrate all GCES Phase II fish databases; this will allow assessment of the population status of the endangered HBC and provide an important resource for investigations of population trends, movement, recruitment, age structure, and health in native fishes. Other actions include monitoring native and non-native fish populations in Grand Canyon, conducting studies on non-native fishes; and continuing hydrological/geochemical monitoring in the LCR. Given the vulnerability and apparent declining status of HBC in Grand Canyon, specific management and conservation actions are recommended to safeguard against further loss of population resources: establishing a captive broodstock of HBC; initiating a genetic management plan for HBC; initiating a predator control program; protecting key tributary confluences and managing tributaries for the benefit of native fishes; and establishing additional reproducing populations of HBC in one of the Grand Canyon tributaries.

## The ADAPTIVE MANAGEMENT PROCESS and RECOVERY of LISTED SPECIES

With the establishment of the AMP, the aquatic environments of Grand and Glen Canyons will be actively managed for the benefit of natural resources and endangered species through an iterative, ongoing management process that includes modification of dam operations and execution of other management actions. The long-term goal of the AMP should be ecosystem restoration and recovery of listed species but the immediate goal is removal of jeopardy, which can be achieved by implementation of the RPA. Four stages of the iterative process were identified: I. Information acquisition: research and monitoring; II. Integration and synthesis of information base; III. Development of models and formulation of management plans and conservation actions; IV. Implementation of management plans and conservation actions. Life history and community models for native and non-native fishes and a conceptual ecosystem model of the Grand Canyon will be developed to guide the formulation and execution of management and conservation actions that will benefit listed and other native species. Synthesis of the existing knowledge base should provide most of the needed information to generate initial life history, community, and conceptual ecosystem models. Feedback from research and monitoring will allow refinement of management actions and the ecosystem model. Because development and implementation of management actions and resulting benefits to endangered species are expected to take some time, conservation actions need to be implemented early in the process in order to avoid potential losses and thereby broaden opportunities for the success of future management and recovery efforts.

## BACKGROUND

One of the purposes of GCES Phase II research (1990-1995) was to gather critical information on endangered and native fishes in the Grand Canyon for the development of alternative dam operational criteria in the Glen Canyon Dam EIS (1995). However, the draft and final EIS were issued before the completion of GCES Phase II final reports (1995-1996). The Final Biological Opinion for Glen Canyon Dam was released in December 1994 and could only utilize preliminary findings of GCES Phase II studies in formulating the RPA. Thus, the EIS and Biological Opinion do not fully reflect or incorporate the information gained in GCES Phase II studies. Another purpose of GCES Phase II studies was to provide a foundation of knowledge for developing and implementing management plans for Grand Canyon natural resources. One of the primary goals of an Adaptive Management Program (AMP) for Grand Canyon should be to implement measures that will reverse or negate jeopardy actions of dam operations to humpback chub and thereby measurably improve the status of the species in Grand Canyon (USBR 1990, 1995)

The Grand Canyon Protection Act (GCPA) of 1992 (PL 102-575) directed the Secretary of the Interior to "*operate Glen Canyon Dam in accordance with the additional criteria and operating plans specified in section 1804 and exercise other authorities under existing law in such a manner as to protect, mitigate adverse impacts to, and improve values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, including but not limited to natural and cultural resources and visitor use.*" (sec. 1802). The GCPA also directed the Secretary of the Interior to "*establish and implement long-term monitoring programs and activities that will ensure that Glen Canyon Dam is operated in a manner consistent with that of section 1802*" (sec. 1804). Also the GCPA directed that "*Long-term monitoring of Glen Canyon Dam shall include any necessary research and studies to determine the effect of the Secretary's actions under section 1804c on the natural, recreational, and cultural resources of Grand Canyon National Park and Glen Canyon National Recreation Area.*" (sec. 1805).

The Glen Canyon Environmental Impact Statement (EIS; USBR 1995) called for an Adaptive Management Program (AMP) to be implemented following the Record of Decision (ROD) by the Secretary of the Interior. The AMP was "*..developed and designed to provide an organization and process for cooperative integration of dam operations, resource protection and management, and monitoring and research information. The AMP is not intended to satisfy all of the mandates in the GCPA. Likewise, the program is not intended to derogate any agency's statutory responsibilities for managing certain resources. The purpose of the AMP would be to develop modifications to Glen Canyon Dam operations and to exercise other authorities under existing laws as provided in the GCPA to protect, mitigate adverse effects to, and improve the values for which the Glen Canyon National Recreation Area and Grand Canyon National Park were established.*" The EIS recommended establishing a research center which would be responsible for "*developing the annual monitoring and research plan, managing all adaptive management research programs, and managing all data collected as part of those programs.*" In this defined role the research center would serve the technical and information needs of the AMP.

A draft Glen Canyon Dam Biological Opinion was issued on October 13, 1993 in response to the Bureau of Reclamation's February 5, 1993 request for section 7 consultation under the Endangered Species Act of 1973, as amended, by the Service on the proposed action to operate Glen Canyon Dam according to operating and other criteria of the Modified Low Fluctuating Flow (MLFF) alternative (USFWS 1994), selected as the preferred alternative for the Draft and Final Glen Canyon Dam Environmental Impact Statement (EIS; USBR 1995). A final Biological Opinion was released on December 21, 1994 in which the Service gave a jeopardy opinion on the operation of the Glen Canyon Dam under the MLFF criteria (USFWS 1994). In the Biological Opinion, the Service stated "*the MLFF.. is likely to jeopardize the continued existence of the humpback chub and razorback sucker and is likely to destroy or adversely modify designated critical habitat.*" In the jeopardy analysis and in the presentation of the Reasonable and Prudent Alternative (RPA), the Service argued that of the alternatives presented in the EIS, only the Seasonally Adjusted Steady Flow (SASF) alternative sufficiently addressed the jeopardy actions of dam operations on the endangered humpback chub and razorback sucker.<sup>1</sup> Common Elements of the MLFF and SASF alternatives include adaptive management (including research and long-term monitoring), flood frequency reduction measures, habitat and beach building flows, establishing a new population of humpback chub, further study of selective withdrawal, and emergency operations exception criteria. Although not an element of the RPA, the SASF alternative was presented as a Conservation Recommendation and recommended in the Service's FWCA report to BOR (USFWS 1994). In the RPA, the Service prescribed implementation of the Common Elements and the MLFF alternative in high water years. During low water years, the RPA prescribed a program of experimental flows (including seasonally adjusted steady flows) to determine the benefits for endangered fishes of Grand Canyon. The Service also called for the implementation of a selective withdrawal program to address the problem of cold water releases from Glen Canyon Dam. A program of related studies to be conducted as part of experimental flows and selective withdrawal programs was prescribed to determine the effects of temperature and river hydrology on the growth, reproduction, recruitment, habitat, and food resources of endangered and native fishes. Also, these related studies are to determine the effect of temperature and hydrology on non-native fishes and their interactions with endangered and native fishes. Finally, the Service called for development of a management plan for the Little Colorado River, "*actions that will help ensure continued existence of the razorback sucker*" in Grand Canyon; and establishing "*a second spawning aggregation of humpback chub downstream of Glen Canyon Dam*" (USFWS 1994).

The only likely impacts of implementing the RPA (and MLFF) on the endangered humpback chub (HBC) and Kanab ambersnail (KAS) are exceeding incidental take and habitat loss from habitat maintenance and building flows. These flows are expected to increase the loss to young-of-year (YOY) and juvenile HBC in the Colorado River. Thus, in the RPM the Service prescribed surveys "*prior to and following tests of habitat and building flows*" to "*determine the number of humpback*

---

<sup>1</sup>Previous Opinions in 1978 and 1987 concluded that BOR's operation of Glen Canyon Dam jeopardized the continued existence of humpback chub in Grand Canyon (USFWS 1978, 1987). The Service has consistently argued that fluctuating releases of cold, hypolimnetic water has prevented successful reproduction and recruitment of humpback chub in the Colorado River and has led to their decline in Grand Canyon since dam closure in 1963.

*chubs suspected to be lost and the relationship of this loss to the Grand Canyon population.*" Information from these surveys will be used to determine levels of incidental take and may be useful in designing future test flows that reduce levels of incidental take. These flows are also expected to result in population and habitat losses for KAS. Thus, in the RPM the Service prescribed surveys of KAS habitat before and after flows exceeding 25,000 cfs. Further, the Service prescribed population and habitat studies of KAS to *"determine specific habitat characteristics required by that species."* In a separate Biological Opinion on Beach/Habitat Building flows (USFWS 1996), the Service prescribed that prior to future habitat maintenance and building flows where more than 10% of the occupied KAS habitat is expected to be inundated by high flows, formal consultation will be initiated. As part of the Conservation Recommendations of that 1996 Biological Opinion, the Service recommended that efforts be undertaken to discover or establish additional populations of KAS or locate suitable sites for establishing additional populations of KAS.

The EIS called for the establishment of a research center (Grand Canyon Monitoring and Research Center - GCMRC) to meet the research and monitoring needs of the AMP. The management objectives of the AMP are broad-based, including water, sediment, native and sportfish, aquatic communities, vegetation and terrestrial wildlife, threatened and endangered species, cultural resources, recreation, and hydropower production. In contrast, the Service is mandated to assist in and be an advocate for the protection and wise management of species (especially those that are listed) and the ecosystems that support these species. The Service is also responsible for recommending reasonable and prudent alternatives to actions by Federal agencies *"that would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species by further reducing the reproduction, numbers, or distribution of that species."* (Section 7 of the Endangered Species Act- 'ESA'). Furthermore, the Service is responsible for developing recovery plans for endangered species and for seeking cooperators among state, federal, tribal, and private entities to implement these plans so that listed species may be recovered. Recovery is achieved when ecosystems are restored to a level where they can support self-sustaining populations of endangered species as viable members of native biotic communities.

Ideally, management and operation of Glen Canyon Dam should include actions that will: 1) reduce or eliminate incidental take and disruption of life histories of listed species; 2) preserve and restore critical habitat; 3) avoid jeopardy to listed species; 4) lead to down-listing and recovery of endangered species. One of the primary purposes of GCES Phase II was to gather information on the effects of the operation of Glen Canyon Dam on the environment of Grand Canyon and its native and listed species. This information can be used to develop management plans for the operation of Glen Canyon Dam that address the four recommendations above. In FY1997, the Flagstaff FRO was asked by the BOR to review information gathered from GCES Phase II in relation to the RPA and RPMs of the Biological Opinion and identify information needs to address implementation of the RPA by the BOR and AMP. In accordance with Section 7(a)(1) of the ESA, the Service has a responsibility to provide recommendations to BOR and the AMP that when implemented, will likely lead to down-listing and recovery of listed species. Active participation in the AMP provides another way for the Service to provide recommendations and guidance that when followed will likely improve the status of listed species.

## I. GLEN CANYON DAM BIOLOGICAL OPINION

The Final Biological Opinion (2-21-93-F-167) on the operation of Glen Canyon Dam under the modified low fluctuating flow (MLFF) alternative of the Final Environmental Impact Statement (EIS) on the Operation of Glen Canyon Dam was released on 21 December 1994 (USFWS 1994). The Opinion found that the MLFF (preferred) alternative recommended by the EIS was "*likely to jeopardize the continued existence of the humpback chub and the razorback sucker and is likely to destroy or adversely modify designated critical habitat.*" As stipulated in Section 7 of the Act, all opinions are based on an evaluation of the current status of the species, environmental baseline, effects of the proposed action, and cumulative effects on the listed species. To jeopardize the continued existence of a species is to engage in an action that would be expected, directly or indirectly, to reduce the likelihood of both the survival and recovery of a listed species. In the Service's evaluation of Effects of Action, two major problems were identified: 1.) the MLFF does not address the issue of cold water releases from Glen Canyon Dam which adversely affects endangered fishes by preventing successful reproduction of adults and growth and recruitment young in mainstem, edge, and backwater habitats while supporting a large population of predatory trout; 2.) the MLFF permits excessive fluctuation of river flow/elevation on a daily basis which adversely affects the quality and quantity of backwater and edge habitats used by listed fishes. The Biological Opinion found that MLFF alternative was "*anticipated to improve conditions over the No Action alternative (EIS; USBR 1995) for the humpback chub, but the likelihood of recovery in the mainstem Colorado River is still appreciably reduced.*" Thus, implementation of the MLFF will not remove jeopardy nor is likely to lead to recovery of endangered fishes in Grand Canyon.

### ELEMENTS OF THE REASONABLE AND PRUDENT ALTERNATIVE

As directed under Section 7 of the ESA, the Service provided a Reasonable and Prudent Alternative (RPA) to actions proposed by BOR for operation of Glen Canyon Dam. The Service believes that the RPA will avoid the likelihood of jeopardizing the continued existence of listed species or the destruction or adverse modification of critical habitat. Continued decline and loss of native species is tied to the decline and damage to natural ecosystems. The success of recovering damaged ecosystems is compromised by the loss of biological species, its functional living components. The recovery of one species independent from another is less likely because of the interdependency and interactions of species in ecosystems. Thus, whole communities must be considered in recovery of species and their ecosystems. Because of the trend of loss of native species continues in Grand Canyon and because actions for one native species may benefit or affect other native species, the viability of the entire native fish community and its ecosystem will be crucial to the removal of jeopardy for humpback chub and razorback sucker. In the RPA, the Service prescribed four elements, that when implemented, will likely lead to removal of jeopardy to endangered fishes of Grand Canyon:

1. Develop an adaptive management program (common EIS element).

The Biological Opinion states that "*Reclamation shall develop an adaptive management program that will include implementation of studies required to determine impact of flows on listed and native fish fauna, recommend further actions to further their conservation, and implement those recommendations as necessary to increase the likelihood of both survival and recovery of the listed species.*" The adaptive management process is an active, iterative learning approach to resource management and is based on deliberate and careful experimental design in the research and monitoring of ecosystem components. Thus, one of the objectives of the Adaptive Management Program (AMP) should be to modify dam operations so that listed species are not jeopardized and recovery is possible. The RPA prescribes the following studies or actions to be implemented within an adaptive management framework to improve the likelihood of survival and recovery of endangered species:

A. *Program of Experimental Flows*

The BOR will conduct "*a program of experimental flows..to include high steady flows in the spring and low steady flows in the summer and fall during low water years (releases of approximately 8.23 maf) to verify an effective flow regime and quantify... effects on endangered and native fish.*" Research design will be based on flows that resemble the natural hydrograph for those seasons as described in the SASF alternative of the EIS and will include high, steady flows in spring (which may include habitat building and maintenance flows), and low, steady flows in summer and fall. During moderate and high water years, the MLFF alternative will be followed.

B. *Selective Withdrawal Program* (common EIS element)

The BOR shall implement a selective withdrawal program for L. Powell/Glen Canyon Dam that will determine feasibility using the following guidelines:

- I. Review historic data and employ modeling to develop possible scenarios of temperature changes in mainstem habitat.
- ii. Conduct experimental research and review of literature and consult with agencies and experts to determine anticipated effects of temperature changes that may result from a selective withdrawal program. Determine the range of temperatures required for growth and recruitment of larval and juvenile native fishes.
- iii. Determine effects of temperature changes on interactions between native and non-native fishes.
- iv. Determine the effects of temperature changes on the food base (algal and invertebrate communities) and fish diseases and parasites.

- v. Evaluate the effects of selective withdrawal on heat budgets and biota of lakes Powell and Mead.
- vi. Evaluate the effects of selective withdrawal level on downstream resources, particularly fine particulate organic matter (FPOM) and important plant nutrients.

*C. Program to study responses of native fishes to temperature and experimental flows*

The BOR will implement a program of studies to determine the effect of various flow and temperature regimes on native fishes in Grand Canyon. The studies will address:

- I. Effects of temperature on reproduction, growth and survivorship of native fishes.
- ii. Relationships among tributary hydrology, reproduction, and abundance of native fishes in mainstem habitats.
- iii. Relationship of mainstem hydrology on near-shore habitat and environments and use by native fishes.
- iv. Biotic interactions between native and non-native fishes.
- v. Humpback chub life history in downstream reaches.
- vi. Food base and food webs and nutrient and energy pathways in downstream reaches.
- vii. Parasites and diseases in endangered and native fishes.

2. Develop a management plan for the Little Colorado River.

The principle objective of this plan is the protection of humpback chub habitat in the Colorado and Little Colorado rivers. BOR will work with the Service, Navajo Nation, Hopi Tribe, National Park Service, Arizona Game and Fish Department, Bureau of Indian Affairs, and other agencies in developing a draft management plan by December 1996.

3. Develop actions that will help ensure continued existence of razorback sucker in Grand Canyon.

The BOR will sponsor a workshop to gather the advice of experts to develop a management plan for razorback sucker in Grand Canyon. The Service will review the results of the workshop and recommend a course of action and develop a Memorandum of Understanding with BOR and other interested parties that outlines the development of the management plan and a schedule of actions to implement.

4. Establish a second spawning aggregation of humpback chub downstream of Glen Canyon Dam (common EIS element).

Using existing scientific information base from Grand Canyon endangered fish research, BOR in consultation with the Service, National Park Service, Arizona Game and Fish Department, and other land management agencies, will make every reasonable effort through funding, facilitating, and provision of technical assistance to implement a program for establishing additional spawning populations of humpback chub in the mainstem Colorado River or tributaries.

#### SCHEDULE AND COORDINATION OF RPA ACTIONS

The Service and the BOR will meet at least annually to review and coordinate implementation of the RPA. Design of the experimental flows and related studies are targeted for completion in October 1996 and targeted for implementation by April 1997. Prior to implementation, the Service will make a determination on the proposed studies, using the existing knowledge base from GCES Phase II and information provided by knowledgeable individuals, as to whether the design of the experimental flows or information to be acquired from related studies will contribute to removal of jeopardy. The date of implementation may be delayed to later in 1997 if there is sufficient progress toward design of studies. If the Service determines that BOR is not making sufficient progress toward implementation of the experimental flows and related studies, the Service will prescribe that Glen Canyon Dam be operated under SASF alternative from April to October beginning in 1998. If the Service determines that adequate studies can not be developed that would provide critical information for removal of jeopardy to endangered fishes, the Service may reinstitute formal consultation. Implicit in this schedule is a delay in the implementation of experimental flows until a low water year occurs, but design of the flows and related studies and execution of some related studies should not be delayed.

#### REASONABLE AND PRUDENT MEASURES TO MINIMIZE INCIDENTAL TAKE

The Biological Opinion also prescribed measures to minimize incidental take of humpback chub and Kanab ambersnail (KAS) and set terms and conditions for exemption from prohibitions under Section 9 of the ESA. These Reasonable and Prudent Measures (RPMs) included:

1. Studies to determine impact of habitat maintenance/building flows on humpback chub YOY and juvenile age classes to assist in establishing levels of incidental take.

Information on size of these age classes will be "*collected prior to and following tests of habitat maintenance and building flows.*" From this research and monitoring effort, "*a method will be developed to determine the number of humpback chubs suspected to be lost and the relationship of this loss to the Grand Canyon population.*"

2. Conduct surveys of KAS habitat before and after scheduled flows >25,000 cfs to document levels of incidental take.

To determine the impact of incidental take, studies of habitat and population ecology of KAS will be conducted. The RPM contained within the Biological Opinion on the Spring 1996 Habitat Building Flow (UC-320, ENV-1.00; 16 February 1996) prescribed that an additional KAS population must be established before future scheduled habitat building flows.

## CONSERVATION RECOMMENDATIONS

As directed under Section 7(a)(1) of the ESA, the Biological Opinion provided conservation recommendations to minimize or avoid adverse effects of proposed actions on listed species or critical habitat. The suggested actions were:

1. Operate Glen Canyon Dam according to the EIS Seasonally Adjusted Steady Flows (SASF) alternative.
2. Monitor peregrine falcon breeding sites in Glen and Grand Canyons.
3. Monitor peregrine populations and habitat use.
4. Monitor populations, habitat use and foraging ecology of wintering bald eagles.
5. Conduct a thorough investigation of KAS ecology.

## II. GCES PHASE II RESEARCH: SUMMARY of FINDINGS

The purpose of GCES Phase II research (1990-1995) was to gather critical information on endangered and native fishes in the Grand Canyon and to provide this information for the development of the Glen Canyon Dam EIS and to provide a foundation for developing management and recovery actions for the endangered humpback chub (USBR 1990, 1995).

### CONTRACTED INFORMATION ACQUISITION FOR GCES PHASE II

Listed below are contracts from GCES Phase II (FY1991-1995) that provided base ecological information on endangered humpback chub and other native fishes in Grand Canyon. Information to be collected was specified in contracts and subsequent amendments awarded by the BOR (USBR 1990). Responsible agency or contractor for providing critical information is noted in each element.

#### *MAINSTEM COLORADO RIVER STUDIES (FY1991-1995)*

Distribution, movement, general habitat use, and population structure of juvenile and adult humpback chub (Bio/West, Contract No. 0-CS-40-09110). Principal Investigator: Richard Valdez, PhD. Field Work FY1991-FY1994; Report Generation FY1995.

Diet of adult humpback chub (Bio/West, Contract No. 0-CS-40-09110). Principal Investigator: Richard Valdez, PhD. Field Work FY1991-1993; Report Generation FY1995.

Distribution and habitat use by early life history stages of humpback chub in backwater and tributary confluence habitats (AGFD, Contract No. 9-FC-40-07940). Principal Investigators: William Persons, Timothy Hoffnagle, PhD. Field work FY1991-FY1995; Report Generation FY1996.

Habitat use by native and exotic fishes in tributaries, including confluences and upstream reaches (USFWS, Interagency Agreement 1-AA-40-10480). Principal Investigators: Owen Gorman, PhD. (Project Coordinator), Stuart Leon, PhD., O. E. Maughan, PhD. Field Work FY1991-FY1994, extended to FY1995; Report Generation FY1994.

#### *LCR STUDIES*

Habitat use by YOY, juvenile, adult and spawning humpback chub (USFWS, Interagency Agreement 1-AA-40-10480). Principal investigators: Owen Gorman, PhD. (Project Coordinator), Stuart Leon, PhD. Field Work FY1991-1994, extended FY1995; Report Generation 1994.

Movement, distribution, and population structure of adult humpback chub (ASU, Contract No. 1-FC-40-10490). Principal investigators: Michael Douglas, PhD., Paul Marsh, PhD. Field Work FY1991-FY1995; Report Generation FY1996.

Movement, distribution, and habitat use by early life history stages of humpback chub (AGFD, Contract No. 9-FC-40-07940). Principal Investigators: William Persons, Robert Clarkson, Anthony Robinson. Field Work FY1991-FY1994; Report Generation FY1995, FY1996.

Geochemistry of LCR waters in relation to humpback chub distribution (NAU). Principal Investigators: Rod Parnell, PhD. and Dana Strength. Co-investigator: Owen Gorman, PhD. Field Work FY1995-FY1996; Report Generation FY1997.

#### *OTHER STUDIES RELATIVE TO ENDANGERED FISHES*

Distribution, movement, and production in macroinvertebrate and benthic communities in the mainstem Colorado River (NAU). Principal investigators: Dean Blinn, PhD. and Joseph Shannon. Field Work FY1991-1994; Report Generation FY1995.

Thermal shock, temperature and growth studies for larval razorback sucker, bonytail chub, and humpback chub (AGFD, Contract No. 9-FC-40-07940). Principal investigators: William Persons, Robert Clarkson. Field Work FY1991-FY1994; Report Generation FY1995.

Synthesis of information on the humpback chub in the Colorado River Basin (NAU, Contract No. 1FC-40-10500). Principal investigator: Charles Minckley, PhD. Report Generation FY1991-FY1993; FY1996.

#### SUMMARY INFORMATION GAINED FROM GCES PHASE II STUDIES

##### *MAINSTEM COLORADO RIVER STUDIES*

Radio telemetry, electrofishing, and passive gear sampling conducted by Bio/West showed a concentration of adult humpback chub (HBC) in the confluence reach of the LCR in the mainstem Colorado River (95.4% of adults were captured between river miles 61.3-76.6) (Valdez and Ryel 1995). Small populations of adult HBC were also found at South Canyon (river mile 30.8), Middle Granite Gorge (river miles 126-129), Pumpkin Springs (river mile 212.5-213.2), and in the vicinity of the small warmwater tributaries (Bright Angel, Shinumo, Kanab, and Havasu creeks). The estimated size of the mainstem adult population ranged from 3300-3800 fish (Valdez and Ryel 1995). Radio telemetry and recapture data showed that adult humpback chub in the mainstem were relatively sedentary and did not move between these aggregations (Valdez and Ryel 1995). The longest movements were observed in the LCR inflow population where some individuals migrated as much as 20 km from the mainstem to spawning areas in the Little Colorado River and then returned to their previous prespawning mainstem locations (Valdez and Ryel 1995). The distribution and appearance of young-of-year (YOY) HBC in the mainstem below the confluence of the LCR indicated that they were derived from this tributary (Valdez and Ryel 1995). Increased abundance of YOY HBC following flooding in the LCR supports this interpretation. YOY did not appear to thrive in mainstem habitats; growth was arrested and there was essentially no recruitment (Valdez

and Ryel 1995). Temperature studies on HBC, bonytail chub and razorback sucker conducted by AGFD suggested that low temperatures arrest the growth of YOY fish, which leads to high mortality and very low recruitment (Lupher and Clarkson 1994; Valdez and Ryel 1995). Seasonal trends in abundance of juvenile HBC suggested these larger fish fared better in mainstem habitats and were not as affected by low temperatures, although growth rates were apparently reduced. However, Valdez and Ryel (1995) estimated that only 1 in 1000 subadults survive three years to adulthood. Studies by AGFD indicated that YOY and juvenile HBC used backwater and edge habitats, however, daily fluctuations in flow appeared to render these habitats too ephemeral to be of use for small fish (Valdez and Ryel 1995, AGFD 1996). Studies by AGFD and FWS showed that all size classes of HBC used confluence reaches of small, warmwater tributaries, but these habitats were extremely rare and small in size compared to habitat needs of the Grand Canyon HBC population (Gorman 1994, AGFD 1996). Adult HBC used larger, deeper habitat associated with large eddy complexes in the mainstem (Valdez and Ryel 1995). Although low temperatures did not appear to negatively affect adult HBC compared to YOY, the low temperatures may have impaired oocyte maturation, and thus may have precluded reproduction in mainstem habitats (Valdez and Ryel 1995). Examination of published physiological studies of related warmwater cyprinid fishes indicated that mainstem temperatures in the vicinity of the LCR confluence (8-10°C) were too cold for gametogenesis, reproduction, embryological development, and larval development (Valdez and Ryel 1995).

## *LCR STUDIES*

### *Humpback chub distribution, movement, and population size*

Adult HBC were distributed from the confluence to Atomizer Dam (a natural travertine dam/reef complex at km 13.5). During late winter and spring, large adult chubs from the Colorado River mainstem staged at the LCR confluence (Valdez and Ryel 1995; Douglas and Marsh 1996a, b) and ascended the LCR and joined resident adults to spawn (Gorman 1994; Gorman and Stone 1997; Valdez and Ryel 1995). Over the period of July 1991 through November 1992, monthly estimates of adult population size ranged from 100s to more than 5000 individuals (Douglas and Marsh, 1996a, b). The population size peaked in spring and early summer and dwindled in the fall and early winter months. Population trends and recapture data indicated an influx of adults from the mainstem Colorado River. Adults presumably returned to the mainstem during summer and fall months (Valdez and Ryel 1995; Douglas and Marsh 1996 a, b; Gorman and Stone 1997). FWS data suggests that smaller adults remained resident in the LCR and larger adult fish were migratory and seasonal residents (Gorman 1994; Gorman and Stone 1997). Densities of adult chub were higher in the upstream reach of their 13.5 km distribution in the LCR (Gorman 1994; Gorman and Stone 1997, Douglas and Marsh 1996a, b).

Population estimates of adult humpback chub from a variety of studies conducted in the LCR and its confluence showed a decline over the period 1982-1992 of approximately 30-80% depending on the specific year of comparison (Douglas and Marsh 1996a). For the period 1982-1988 population estimates for the LCR confluence ranged from 1800-7060 compared to 1320 for 1992. For 1982,

Kaeding and Zimmerman (1982) estimated a population size for the entire LCR to be 7000-8000 but for 1992 Douglas and Marsh (1996a) estimated the population to be 4300-4600. However, these comparisons are weakened by different sampling designs and methods of estimating population size among the various investigators; comparisons of estimates from one study are more convincing. In further analysis of their 1991-1995 recapture data, Douglas and Marsh (1996b) showed a decline from ~6000 adults in 1991 to <2000 in 1995. Most of this decline was attributed to a sharp reduction of survivorship of smaller-sized adults after 1993. Reasons for reduced survivorship in smaller adults was unknown. The decline in the estimated population size of adult humpback chub in the LCR over the period 1991-1995 and since 1982 in the confluence was accompanied by a decline in condition factor; analysis of historic catch data for the LCR humpback chub population showed a decline in condition of adult fish from the late 1970s to present (Meretsky et al. 1996). However, the decline in condition factor may be an artifact of small samples of large adults in the analysis after 1990. Population estimates and condition factor analysis provided two lines of evidence that the humpback chub population in Grand Canyon may have undergone a decline since the late 1970s. Additional analyses using an integrated data set of mainstem and LCR capture data will provide a more accurate assessment of recent (1991-1995) population trends for humpback chub in Grand Canyon.

#### *Humpback chub distribution and geochemical conditions*

Atomizer Falls (km 13.5) represented the upstream terminus of humpback chub distribution in the LCR. The source of perennial base flow comes from Blue Springs at 20-21 km upstream. These springs were highly charged with bicarbonate, and degassing resulted in the precipitation of calcium carbonate and formation of travertine deposits. At base flow, catastrophic precipitation occurred between Chute Falls and upper Atomizer Falls (km 14-13.5); over this 500 m reach the water turned from glass-clear to milky blue. This was also the most upstream location of large travertine deposits. Studies conducted by FWS, AGFD, and NAU have not provided a clear answer to why HBC are not found above Atomizer Falls (Mattes 1993; Robinson et al. 1995; Strength 1997)

#### *Habitat use by humpback chub*

Small YOY HBC (40-70 mm TL) used highly structured edge habitat (<3 m from shore) and occupied middle to lower water column positions, and at about 75 mm TL, began using deeper water, main channel habitats (Gorman et al. 1993, Gorman 1994). In sharp contrast to adults, YOY were diurnally active. Adult HBC ( $\geq 3$  yr old,  $>200$  mm TL) used deep water areas ( $>1$  m) with high vertical structure along stream banks or in mid-channel areas and occupied near-bottom water column positions. At night, adults were more active and moved into shallower habitats and showed increased use of middle and upper water column positions. Sub-adult HBC (~2 yr old, 150-200 mm TL) habitat use was very similar to adults and differed only in degree: adults used deeper areas with high vertical structure more frequently than subadults. Juvenile (yearling) HBC (100-150 mm TL) showed considerable overlap in habitat use with YOY and adults. In general, juveniles used edge and main channel habitat of moderate structure, occupied the lower 1/3 of the water column, and were intermediate in diel activity patterns.

### *Humpback chub growth and seasonal patterns*

YOY HBC reached a mean size of 75-85 mm TL by early fall (Gorman 1994). 5-10% of YOY exceeded 100 mm TL after their first summer. In most years, rearing habitats remained stable for the first three months (May-July), and after that time were often subjected to muddy spates triggered by summer conventional rainstorms. By July most April-hatched YOY were 50-60mm TL, a size at which they were competent swimmers. If summer spates were delayed to late summer (as in 1993), most YOY HBC were not displaced by these late-season floods and remained abundant in the LCR through fall and winter. Early summer flooding can flush most YOY from the system as apparently happened in 1992, resulting in the loss of the 1992 year class.

Most yearlings reached ~100 mm TL by the end of their first year (April-May) (Gorman 1994). By mid-summer of their second year, they were typically 50-60 mm longer than the emerging population of YOY. Presumably, yearlings need to reach a minimum size before their first anniversary, otherwise, they would use habitat and food resources that may be too similar to YOY that appear in large numbers in the early summer. Most two-year-old subadults reached 150-180 mm TL at the completion of their second year. Most three-year-old fish were >200 mm TL at the completion of their third year. This observed schedule of growth is consistent with Kaeding and Zimmerman's (1983) previous study of HBC in the LCR.

### *Humpback chub spawning habitat*

During spring months (March-May) ripe adult male HBC aggregated in discrete habitats of high vertical structure (characterized by increased angular variation of bottom profile), moderate depth (1-2 m), and slow to moderate currents (0.2-0.70 m/s), and had conspicuous gravel substrates (Gorman and Stone 1997). These areas occurred frequently below travertine dam/reef complexes. Non-ripe fish did not aggregate with ripe males and were relatively dispersed throughout available habitat. Ripe females were relatively rare and were usually captured in areas where ripe male aggregations were found. Areas containing ripe male aggregations were identified as putative spawning habitat (Gorman and Stone 1997).

### *Humpback chub reproduction*

Although there is evidence that sporadic spawning can occur in any month (Minckley 1996), the peak of successful spawning, i.e., those efforts that result in the presence of larval and YOY fish, typically occurred after the last winter floods, usually during the period early mid-April to mid-May (Robinson et al. 1996; Gorman and Stone 1997). Sampling for larval HBC with drift nets and netting of stream margins indicated that most successful spawning occurred in March-May and spawning activity appeared to taper off during May (Robinson et al. 1996). Predicted timing of spawning from emergence of larvae was supported by peaks in abundance of ripe adults, proportion of tuberculate adults, proportion of adults in spawning coloration, and a rapid decline in relative condition (Gorman and Stone 1997). Almost all fish in spawning condition were >200 mm TL and thus were  $\geq 3$  years of age (Gorman and Stone 1997); this schedule for age of sexual maturity is

consistent with Kaeding and Zimmerman's (1983) previous work on HBC in the LCR.

FWS conducted a pilot study to determine techniques for field collection and cryopreservation of sperm from the endangered big-river fishes of the Colorado River (razorback sucker, Colorado squawfish, bonytail chub, humpback chub) (Gorman 1994, 1995, 1996). In the spring of 1995 FWS researchers conducted research on collection, evaluation, and cryopreservation of humpback chub sperm (Gorman 1995). Application of this research will be invaluable in future recovery efforts by aiding in establishment of captive broodstocks and production of humpback chub for recovery actions.

### *OTHER TRIBUTARY STUDIES*

The Flagstaff FRO was contracted to assess habitat and fisheries resources of the small tributaries (Paria, Bright Angel, Deer, Shinumo, Tapeats, Kanab, and Havasu) of the Colorado River in Grand Canyon (USBR 1990). In addition, the Flagstaff FRO was to evaluate the tributaries for their potential to support additional populations of humpback chub. Most tributaries were dominated by native fishes but colder streams (Bright Angel, Shinumo, Tapeats) supported large populations of rainbow and brown trout (Allan 1993, Otis 1994, Otis and Maughan 1994, Gorman 1994). Humpback chub were captured or observed in the confluence reaches of some streams (Bright Angel, Shinumo, Kanab, Havasu) (Otis and Maughan 1994, Gorman 1994). Tapeats Creek was dominated by rainbow trout and supported a small population of speckled dace (Otis and Maughan 1994, Gorman 1994). The Paria River was dominated by speckled dace but was also a focus of flannelmouth sucker aggregation and spawning in spring months (Weiss 1993). Flannelmouth suckers also ascended Bright Angel Creek to spawn during spring months (Otis 1994, Otis and Maughan 1994). While large bluehead suckers were captured in the mainstem (Valdez and Ryel 1995), they were rarely captured in tributaries other than the LCR (Gorman 1994). Bluehead suckers matured at a small size in some tributaries (Bright Angel, Shinumo, Kanab, and Havasu) and successfully reproduced (Allen 1993, Otis 1994, Otis and Maughan 1994, Gorman 1994). Only Havasu Creek provided an array of available habitat that matched habitat used by humpback chub in the LCR (Gorman 1994).

### III. RECOMMENDATIONS for RESEARCH, MONITORING, and MANAGEMENT to ADDRESS the ELEMENTS of the GLEN CANYON DAM BIOLOGICAL OPINION

Under the present flow conditions in the mainstem Colorado River in Grand Canyon, native fishes are exposed to an environment of cold, thermally stable temperatures but one that undergoes significant fluctuations in flow on a daily basis. Chronic daily fluctuations of cold water have direct and indirect impacts and preclude completion of life histories for most native fishes in mainstem habitats (Kaeding and Zimmerman 1983; Wydoski and Hamill 1991, Tyus 1992, Lupher and Clarkson 1994, Clarkson et al. 1994, Valdez and Ryel 1995). Direct impacts on native fishes include suppression of gametogenesis in adults and embryogenesis in fertilized eggs (Hamman 1982, Marsh 1985), and reduced growth rates and reduced swimming ability in YOY and juvenile fish (Bulkley et al. 1982; Lupher and Clarkson 1994; Childs and Clarkson 1997). Indirect effects include rendering marginal edge habitats unstable and unproductive, suppression of food resources and cover, and lack of warming of edge habitats (AGFD 1996). More information is needed to better define the physical and biological requirements for completion of life histories of native fishes in mainstem habitats. If these requirements are attainable under a subset of the range of dam operations, then specific actions can be implemented that will allow re-establishment of a mainstem spawning population of HBC. However, if studies indicate little likelihood of attaining conditions conducive to completion of HBC life history in the mainstem, other management solutions must be sought. Presented below are recommended studies guided by the RPA and RPM that address implementation of a program of experimental flows (RPA element 1) and the information needs of the AMP for a more complete understanding of HBC life history and the potential for the mainstem Colorado River to support this endangered species.

#### *RECOMMENDED MAINSTEM and TRIBUTARY RESEARCH and MONITORING*

The recommended studies outlined below address Glen Canyon Dam Biological Opinion RPA element 1, develop an adaptive management program for Grand Canyon; RPA element 1A, conduct a program of experimental flows; RPA element 1B, determine feasibility of a selective withdrawal program for Lake Powell; RPA element 1C, research program on effects of temperature and flows on humpback chub;

##### 1. Effect of experimental flows on thermal warming of mainstem habitats and native and non-native fishes. (RPA 1A; 1B ii, iii, iv; 1C i-vii)

Although it is apparent that cold water and fluctuating flows in the mainstem Colorado River have precluded a reproducing humpback chub population (Clarkson et. al, 1994), the potential benefits of stabilized low flows and increased water temperature has received minimal experimental evaluation. Stabilization of flows and increased water temperatures may be a necessary first step in the recovery of a mainstem humpback chub population, but possible consequences include increased incidence of diseases, exotic fish competitors, and exotic predators. Listed below are recommended

studies as outlined in the RPA that address effects of flow regimes (experimental flows) and thermal warming on mainstem environments and native fishes:

- i. Determine the effects of temperature on reproduction, growth and survivorship of native fishes, especially listed species.
- ii. Determine the range of temperatures required for reproduction, growth and successful recruitment of larval and juvenile native fishes, especially listed species.
- iii. Determine the effects of elevated temperature and stabilized flows on interactions between native and non-native fishes. Develop management strategies that can minimize potential negative impacts.
- iv. Determine the relationship of mainstem hydrology (high, low, stable, fluctuating flows within range of dam operations) on near-shore habitat and environments and use by native fishes.
- v. Determine the relationships between mainstem hydrology (high, low, stable, fluctuating flows within range of dam operations) and tributary ponding and hydrology and the reproduction, abundance and survivorship of native fishes.
- vi. Determine the effects of elevated temperature and stabilized flows on the food base (algal and invertebrate communities). Studies should address effects on fine particulate organic matter (FPOM) and important plant nutrients.
- vii. Assess the effect of increased temperature and stabilized flows on incidence of fish diseases and parasites. Baseline studies are needed to evaluate effects of changing environmental conditions.

## 2. Mainstem Colorado River habitat studies. (RPA 1A; 1B i; 1C iii)

At present, large adult humpback chub are known to occur in the Colorado River mainstem, particularly in the vicinity of the LCR confluence. However, YOY humpback chub that were found in the mainstem during GCES Phase II did not persist (Valdez and Ryel 1995). This apparent loss is explained by arrested growth under cold water conditions in the mainstem (Lupher and Clarkson, 1994). Even if the temperature problem were corrected, YOY humpback chub may not persist because of inappropriate or unstable habitat under fluctuating flows.

The largest population of reproducing HBC occurs in the LCR which serves as a model of habitat use for that species. The Flagstaff FRO inventoried available habitat and described habitat use by HBC and other native fishes in the LCR and other tributaries in Grand Canyon using a point-sample, multivariate microhabitat approach (Gorman 1988, 1994). Fish sampling and habitat assessment in the mainstem used a subjective macrohabitat approach, and comparable sampling units, e.g.

backwaters, debris fans, eddy return channels, talus shorelines, do not occur in the LCR. Thus, in GCES Phase II, there was no common currency of habitat assessment between the LCR and the mainstem. In order to better understand the potential for the mainstem to support all life history stages of HBC, available habitat in the mainstem, particularly in areas associated with shorelines and eddies that are likely to be used by YOY and juvenile HBC, need to be compared with habitat used by humpback chub in the LCR at micro- and meso-habitats levels. Furthermore, mainstem habitat needs to be inventoried using methods compatible with those used by FWS in the LCR and other tributaries (e.g., Gorman 1994). Ideally, mainstem habitat should be inventoried under conditions of stable and fluctuating flows to assess possible benefits of prolonged periods of stable flows to marginal habitats and the resident fish community. Assessment of mainstem habitat relative to that in the LCR will indicate the potential for the mainstem to support a reproducing population of humpback chub once other detrimental factors, i.e., low temperature and fluctuating flows, are resolved.

i. Mainstem habitats under fluctuating flows (RPA 1C iii)

Throughout GCES Phase II, AGFD studied small backwaters and Bio/West studied a variety of shoreline types along the Colorado River mainstem at different flows. Studies of small mainstem backwaters showed that daily fluctuating flows do not permit appreciable warming which would benefit YOY HBC that may use these habitats (AGFD 1996). Bio/West found YOY and juvenile HBC to be highly associated with vegetated or talus shorelines or debris fans with low current velocities (Valdez and Ryel 1995). Fluctuating flows also suppress growth of macrophytes and associated macroinvertebrate communities which would provide food and cover for YOY native fishes. Direct comparisons with LCR HBC/habitat studies are not possible because AGFD and Bio/West used different methodologies than FWS to sample fish and measure habitat.

ii. Mainstem habitats under seasonally adjusted steady flows (RPA 1C iii)

Edge and backwater habitats under conditions of steady low flows have not been studied extensively because of a lack of opportunity. A comparison of temperatures in 4 backwaters during 4 days of fluctuating and 3 days of steady low flows in May 1994 showed that backwaters warm significantly during steady low flows (Hoffnagle 1996). More studies are needed to determine the potential for these areas to provide nursery habitat for YOY native fishes.

3. Mainstem and tributary food resources for native fishes. (RPA 1C vi)

Limited studies of diet of adult humpback chub were conducted by Bio/West (Valdez and Ryel 1995) but parallel studies were not performed on YOY and juvenile HBC in the mainstem. Inventories of macroinvertebrate communities were conducted in the mainstem by NAU and AGFD, but the two studies employed different methodologies and were not integrated with native fish sampling, diet studies, and habitat measurements. In comparison to the mainstem, few studies of food resources were conducted in tributaries, although tributaries are critical environments for spawning and rearing of native fishes in Grand Canyon. More integrated studies are needed to better define the available

food resources for HBC and other native fishes and relate these resources to habitat, distribution of native fishes, and diet.

#### 4. Native fishes: temperature, growth/survivorship, and swimming performance. (RPA 1B ii; 1C i)

AGFD conducted temperature shock and low temperature growth studies with humpback chub, bonytail chub, and razorback sucker (Lupher and Clarkson 1994). However, these studies only used small YOY fish < 50 mm TL. Bulkley et al. (1982) showed that swimming performance in HBC 73-134 mm TL was greatly diminished at 14°C compared to 20°C. Much more work is needed to better understand the effects of suboptimal temperatures on growth and survivorship of native fishes. For example, if temperatures in the mainstem are elevated from 8-10°C to 13-15 °C (estimated temperature increase at the LCR confluence with multi-level intake structure (MLIS) on Glen Canyon Dam), this may not permit growth to required size to avoid high over-winter mortality, or, if the temperatures are higher, it may be only for a brief period which will not result in sufficient growth in YOY fish prior to winter. Lower than optimal temperature may also adversely affect swimming performance in YOY fish so that drift rates and resulting mortality are much higher than is observed in the LCR. Another important question is the effect of temperature on growth and survivorship of resident exotics such as fathead minnow. It is possible that elevated temperatures from operation of the MLIS may benefit exotics more than natives, but the timing of the release of warm water may shift the benefit to natives. A series of experiments to determine the growth and survivorship of native fishes at temperatures ranging from 10-24°C for a period of a year or more would identify required temperatures for sufficient growth and survivorship to sub-adult size.

#### 5. Diseases of Grand Canyon fishes. (RPA 1B vi; 1C vii)

As yet there has not been a concerted study of diseases of native fishes of the Grand Canyon. Over the course of GCES Phase II, it was apparent that native fishes and introduced trouts were suffering from an array of epizootics caused by a variety of parasitic organisms. For example, most fish captured in Kanab Creek in June 1993 by FWS biologists carried one or more *Lernaea* (Gorman 1994). During July 1994, the Service encountered large numbers of dead or dying fish in Kanab Creek (Gorman, pers. obs.). In August 1993, *Lernaea* were commonly found attached to YOY humpback chub in the LCR (Gorman 1994). *Lernaea* infestations were even more prevalent among LCR humpback chub during spring 1994 (Gorman, pers. obs.). Asian tapeworm (*Bothriocephalus acheilognathi*) was first observed in HBC in the LCR in 1990 (Minckley 1990). Over the period 1990-1994 AGFD surveys in the Grand Canyon determined the mean prevalence of Asian tapeworm in HBC was >20% (Brouder and Hoffnagle 1997, Clarkson et al. 1997). At present, there is no basis for understanding the causes, dynamics, or ultimate impact of these diseases on fish populations.

Implementing a long-term monitoring program for fish diseases is needed to establish a baseline for fish diseases in the Grand Canyon. Ideally, this program should be fully integrated into other monitoring programs so that fish health variables are related to environmental and population measures. Baseline data are needed prior to implementation of flow and/or temperature modification of dam discharge to better understand changes in epidemiology of fish diseases when shifting from

fluctuating to seasonally stable flows or cold to warm water conditions. Should changes in the status of fish health occur in the future, these can be understood in relation to past conditions and appropriate management recommendations can be made.

#### 6. Study of native fishes in Grand Canyon. (RPA 1C I, ii, iii, iv, vii)

During GCES Phase II a program to PIT tag all native fishes (humpback chub, flannelmouth sucker, bluehead sucker, razorback sucker) >150mm TL was implemented. This effort allowed researchers to track movement and survival of large numbers of native fishes. Because most field sampling efforts have focused on humpback chub, there has been less attention given to other native fishes.

Weiss (1993) found that large flannelmouth sucker moved long distances within the Grand Canyon and many returned to the Paria during the spawning season. The size structure of the population consisted of many large adult fish with a paucity of intermediate size classes, suggesting an aging population without recruitment, similar to the razorback sucker population in Lake Mohave (Minckley et al. 1991). This situation may be the result of limited recruitment of large adult flannelmouth sucker following closure of Glen Canyon Dam. If this is true, most large flannelmouth suckers in Grand Canyon are >30 years old and the population may decline rapidly when ecological longevity is reached. To remedy the lack of knowledge of flannelmouth sucker, special efforts to study this species downstream of Glen Canyon Dam should be implemented.

Relatively little is known about bluehead sucker in the Grand Canyon. Although most tributaries have large populations of bluehead suckers, fish in these streams are relatively small (100-200 mm TL) and reproduce at a small size (Allan 1993; Otis 1994; Otis and Maughan 1994). In contrast, large individuals (>300 mm TL) are captured in the mainstem and tributary confluences. The relationships between mainstem and tributary bluehead suckers are unknown. Because flannelmouth and bluehead sucker are already captured and tagged along with humpback chub, expansion of effort to learn more about these suckers should be relatively untaxing. These studies should also consider the possible benefits of flow and thermal modification of the mainstem environment to these species.

#### 7. Environments and fish communities in Grand Canyon tributaries. (RPA 1C ii)

GCES Phase II research demonstrated that most native fishes in the Grand Canyon (HBC, flannelmouth sucker, bluehead sucker, and to some degree speckled dace) are dependent on the tributaries for spawning, nursery habitat and rearing of young adult fish (Gorman 1994, Gorman and Stone 1997, Otis and Maughan 1994, Valdez and Ryel 1995). The mainstem HBC, flannelmouth sucker and bluehead sucker populations are dependent on the LCR for spawning and rearing (Gorman 1994, Valdez and Ryel 1995). The smaller tributaries (Paria, Bright Angel, Kanab) are used by flannelmouth sucker for spawning (Weiss 1993, Otis 1994, Otis and Maughan 1994). These tributaries and others (Shinumo, Havasu) also support reproducing populations of bluehead sucker and speckled dace (Allan 1993, Gorman 1994, Otis 1994, Otis and Maughan 1994). Lower reaches of Bright Angel, Shinumo, Kanab and Havasu were frequented by juvenile and adult humpback chub (Gorman 1994, Otis and Maughan 1994). These tributaries also support resident populations of

reproducing non-native fish (e.g., channel catfish, fathead minnow, plains killifish, brown trout, rainbow trout) which can colonize mainstem habitats (Gorman 1994, Otis and Maughan 1994). Further studies of the smaller Grand Canyon tributaries are needed to assess year-to-year and seasonal variation in habitat structure and resident native and non-native fish assemblages. Thus far, the Flagstaff FRO described available habitat in the tributaries along with their resident fish assemblages during annual summer research trips in 1993-1995 (Gorman 1994). These past studies do not provide a seasonal or long-term perspective for the range of conditions and population dynamics in these tributaries. Such information may be critical for developing management plans for native and non-native fishes in Grand Canyon streams

Areas where further information on smaller Grand Canyon tributaries is needed:

*influence of year-to-year variation in climate and hydrology on tributaries*

available habitat

habitat use by resident native and non-native fishes

reproduction by native and non-native fishes

fish population structure and dynamics

productivity and food resources

diet of native and non-native fishes

*influence of fluctuating vs. steady mainstem flows on tributary confluence reaches*

available habitat

habitat use by native and non-native fishes

temperature

productivity and food resources

**RECOMMENDED LITTLE COLORADO RIVER RESEARCH and MONITORING**  
(RPA 1B ii, iii, iv; 1C I, ii, iv, vii; 2)

GCES Phase II research demonstrated that the continued presence of HBC in Grand Canyon is dependent on the LCR environment for spawning, nursery habitat and rearing of young adult fish. Because HBC are able to complete their life history in the LCR, this system serves as model for all monitoring and studies of the species. Continued monitoring and research on the humpback chub population in the LCR is necessary to provide a more complete picture of the ecology of the species (although at reduced levels compared to GCES Phase II). Humpback chub are long-lived (>20 years) and comprehensive ecological studies should be on the same time scale. Also, there is considerable year-to-year variation in climate and population dynamics (Gorman 1994, Douglas and Marsh 1996b). For example, habitat use during a "good" reproductive year might be very different than during a lean year when population densities are much lower. Because HBC have long life spans, the cumulative effect of cyclic environmental processes over the past decade or longer determines the structure and status of the present population. Only a long-term monitoring and research program will allow a better understanding of the environmental conditions and ecology of

recruitment bottlenecks in humpback chub life history and of factors critical to long-term population persistence. Studies of thermal and food requirements, spawning habitat, and YOY habitat use will provide baseline information upon which to evaluate the potential for mainstem habitats to support all life history stages of the species.

*Areas where further information on humpback chub is needed are:*

- population ecology (age/size structure, survivorship)
- spawning ecology and habitat use, particularly identifying specific spawning sites
- contribution of migrating humpback chub to spawning effort/success
- habitat use in the confluence
- ecology and habitat use by post-larval fish
- habitat use by YOY and juvenile fish at lower population densities
- thermal requirements and growth of early life history stages
- food resources and diet (including seasonal and ontogenetic perspectives)
- stream productivity and energy sources (seasonal, year-to-year)
- assessment of movement and home range in relation to age and size
- biotic interactions with non-native fishes

The recommended LCR studies below address Glen Canyon Dam Biological Opinion RPA element 1, development of an adaptive management plan for native fishes of the Grand Canyon; RPA element 1C, research program on effects of temperature and flows on humpback chub; RPA element 2, develop a management plan for the Little Colorado River; RPA element 4, establish a second spawning aggregation of humpback chub. The LCR Management Plan was one of 7 conservation measures developed jointly by BOR, FWS, AGFD, NPS and the Navajo Nation Natural Heritage Program in 1990 (USBR 1990, USFWS 1990). The LCR management plan should serve to guide the collection and synthesis of information on HBC and other native fishes in the LCR, identify and protect critical resources, and provide an interface for integration with the Grand Canyon AMP.

8. Food resources and diet studies in the LCR. (RPA 1B iv, 1C vi)

While GCES Phase II included studies of food resources and diet for the endangered humpback chub in the mainstem Colorado River (Valdez and Ryel 1995), parallel studies were not conducted in the LCR, the model system for that species. Thus, within the model system, temporal variation in survivorship, growth, and diet of various life history stages of HBC in relation to food resources, autochthonous production, and allochthonous inputs is poorly understood. The lack of baseline studies of diet and food resources in the LCR impairs understanding of the potential for mainstem habitats to support various life history stages of HBC.

9. HBC spawning habitat in the LCR. (RPA 1C I, ii, v, )

Studies of habitat use by the Flagstaff FRO have identified habitat associations with putative spawning aggregations in the LCR (Gorman and Stone 1997). Further work is needed to identify these spawning habitats and map their locations. This work will allow a better understanding of

habitat use by spawning HBC in the LCR and can serve as a model for assessing the potential of mainstem and tributary habitats to support spawning of HBC.

10. Growth and recruitment of HBC in the LCR. (RPA 1B ii, 1C I, ii)

The LCR offers an excellent opportunity to study the relationships between temperature, food resources and growth in YOY HBC. Field studies should be conducted in parallel with laboratory/hatchery temperature and growth studies recommended in section 4 above. Growth/temperature/diet studies in the LCR will provide a model that shows minimum thermal and food requirements for a successfully reproducing HBC population in the mainstem.

11. HBC early life history studies in the LCR. (RPA 1C I, ii, v)

AGFD studies of early life history stages of HBC in the LCR provided information of the timing of emergence of larval HBC relative to probable spawning, their distribution, probable reaches where spawning takes place, relative amount of larval fish produced, drift and loss of larval fish from the LCR, and general characteristics of habitat used by larval fishes (Robinson et al. 1996). Further information is needed (or synthesis of existing data) on habitat use, temperature regimes, food resources, diet, growth of larval fishes and causes of mortality or other loss.

12. Effects of non-native fishes on HBC. (RPA 1B iii, 1C iv)

The LCR provides a natural laboratory for evaluating the effects of non-native fishes on HBC under warm, seasonally stable flows. Biotic interactions that can be readily investigated include: competition from fathead minnows, red shiners, plains killifish and common carp and YOY and juvenile HBC, predation on YOY HBC by red shiners and fathead minnows, and predation on juvenile and adult HBC by channel catfish.

*RECOMMENDED MANAGEMENT AND CONSERVATION ACTIONS*

The following recommendations address RPA element 3, develop a management plan for razorback sucker; RPA element 4, establish a second spawning aggregation of HBC.

13. Development of a management plan for maintenance of razorback sucker in Grand Canyon. (RPA 3)

In January, 1996, the Bureau of Reclamation held a workshop to enlist the advice and knowledge of experts for the development of a management plan for razorback sucker in Grand Canyon. GCES Phase II studies demonstrated that razorback sucker and hybrids are present in very low numbers in Grand Canyon. Their rarity appears to be caused by a failure to reproduce under present altered riverine conditions. Some scientists at the workshop expressed the opinion that the Colorado River

in Grand Canyon may be an important factor in recovery of this species in the Lower Basin. However, recovery of the Grand Canyon razorback sucker population must be linked to management and recovery efforts in Lake Mead along with a vigorous exotic fish control program. Much more work is needed to develop a management plan for this species in Grand Canyon which should be integrated with other Lower Basin efforts for this species.

14. Establish a second spawning aggregation of humpback chub downstream of Glen Canyon Dam.  
(RPA 4)

As stated in the Biological Opinion, BOR is expected to *"make every reasonable effort through funding, facilitating, and providing technical assistance to establish a program for additional spawning aggregations (or populations depending on genetic status) in the mainstem or tributaries."* This conservation action is one of 7 conservation measures developed jointly by BOR, FWS, AGFD, NPS, and Navajo Nation Natural Heritage Program in 1990 (USBR 1990, USFWS 1990) and is yet to be implemented. BOR and the Service should consider forming a team of scientists and resource managers to address establishing additional spawning populations of HBC in Grand Canyon. This team should assess the possibility of re-establishing a mainstem population and/or establishing populations in tributary streams. The team should consider interim measures if establishing new populations appears to be a lengthy process. The team should develop a report summarizing their analyses and proposed management actions to be submitted to the Service and AMP for consideration.

15. Conduct studies to determine impacts of habitat maintenance and building flows on YOY and juvenile classes of humpback chub. (Incidental Take RPM and Terms and Conditions for Implementation, elements 1, 2.)

In the 1994 Biological Opinion, the Service prescribed studies to determine the effect of test and maintenance flows on incidental take of young HBC. These studies will help to determine the level of future incidental take associated with these flows, and determine the impact of these flows on the survival of juvenile age classes of HBC. Such studies should be integrated into existing monitoring of HBC in Grand Canyon to better identify the impact of such flows in the context of normal population dynamics. Monitoring should be done prior to and immediately after test flows in areas where juvenile HBC are known or suspected to occur. These studies can potentially provide information for designing test/maintenance flows with reduced impact on juvenile HBC in Grand Canyon.

#### IV. RECOMMENDED RESEARCH, MONITORING, and MANAGEMENT and CONSERVATION ACTIONS for the ADAPTIVE MANAGEMENT PROGRAM

The signing of the ROD in October 1996 marked the beginning of a new era in which Glen Canyon Dam is to be operated through an Adaptive Management Program (AMP) for the benefit of the natural resources of Grand Canyon. A primary goal of the AMP should be to develop and implement management plans that lead to removal of jeopardy to listed species. While removal of jeopardy is achieved when the RPA is fully implemented, it is in the interests of all agencies involved to seek recovery of listed species. Species recovery is achieved when ecosystems are sufficiently restored to allow populations of listed species to be self-sustaining, viable components of biological communities and these populations are protected from risks associated with anthropogenic activities. The benefit of recovery of listed species is that it signals the restoration of ecosystem health and function. Ideally, recovery of the endangered HBC in Grand Canyon will be achieved when the environment of the Colorado River is sufficiently restored to a natural condition to allow the re-establishment of a reproducing mainstem population. However, re-establishing a reproducing population in the mainstem may not be possible within the current range of dam operations, e.g., hypolimnetic releases are too cold and there is presently no thermal warming capability. A timetable for correcting these limitations are difficult to project because of legal and budgetary constraints. The present population of HBC in Grand Canyon is almost entirely dependent on the LCR, which is relatively vulnerable to catastrophic loss from toxic spills and declining flow and water quality from overuse of ground waters by rapidly expanding human populations in northern Arizona. Without some management intervention before more permanent solutions are found for recovery of HBC, there is significant risk of future population loss or extirpation of HBC in Grand Canyon. An interim measure might include establishing an additional spawning population of HBC in one of the tributaries of the Colorado River in Grand Canyon.

The principal effect of past Federal actions (dam operations) on HBC has been the reduction of populations in the mainstem Colorado River. The chronic fluctuating release of cold water from Glen Canyon Dam has resulted in the elimination of successful reproduction of HBC in the mainstem and a lack of recruitment of YOY fish from the LCR in mainstem environments. In the *Discussion of Effects and Analysis of Jeopardy and Adverse Modification* contained within the Biological Opinion (USFWS 1994), the Service acknowledged these impacts of dam operations and that the presence of HBC in Grand Canyon remains highly dependent on the remaining LCR population which is vulnerable to loss from environmental insult within the LCR drainage. In the analysis of jeopardy actions, the Service considered "*the aggregate effects of everything that has led to the species' current status, all future non-Federal activities, and the proposed action*" (implementing the MLFF Preferred Alternative). The Service took the position that because of implementation of the proposed action, "*the likelihood of recovery in the mainstem Colorado River is still appreciably reduced.*" As interim flows were instituted in 1991 and are similar to MLFF, the HBC population has essentially been under the MLFF over the past 6 years and thus represents a test of the effect of that Federal action on the status of HBC. Thus, a continuing decline in the status of HBC in Grand Canyon may not be viewed as an unexpected result of the proposed action. In any case, synthesis

of findings from GCES Phase II (1991-1995) and Interim and Transition Monitoring (1996-1999) will reveal whether or not implementation of MLFF has significantly improved opportunities for recovery of HBC in Grand Canyon.

Preliminary results of GCES Phase II studies suggest that the HBC population in Grand Canyon may be in decline (Douglas and Marsh 1996a, 1996b; Meretsky et al. 1996). If additional analysis of integrated GCES Phase II data shows that the Grand Canyon HBC population is declining, actions should be implemented to reduce the likelihood of extirpation by protecting genetic resources and stabilizing and reversing the causes of the decline. Research efforts should be focused on understanding the cause of the decline and whether it is the result of cumulative changes in the Grand Canyon ecosystem brought about by the operation of Glen Canyon Dam. This research can also address whether future management actions under consideration, e.g., temperature control devices and more natural steady flow regimes, may remedy the problem.

In the Biological Opinion the term *Conservation Recommendations* was defined as "*Service suggestions regarding discretionary agency activities to minimize or avoid adverse effects of the proposed action on listed species or critical habitat or regarding the development of information.*" In this report the term *management and conservation actions* is used to mean recommended actions that will safeguard endangered species or critical habitat against further loss and at the same time provide opportunities for recovery. Because the recommended actions are guided by recovery goals, they are addressed to interested parties and all resource management agencies that have responsibility for management and recovery of endangered species. The recommendations are especially addressed to the AMP, as it represents an omnibus group of stakeholders that has responsibility for guiding and directing the management of Grand Canyon natural resources.

## *RECOMMENDED RESEARCH AND MONITORING ACTIVITIES*

The following research and monitoring activities are recommended to further the Grand Canyon AMP in wise management and conservation of native fishes and recovery of endangered HBC using an ecosystem approach:

### 1. Integration of GCES Phase II fish databases.

There is a critical need to integrate all GCES Phase II fish databases. This is a necessary first step before assessments of the status of endangered HBC and other native fish populations in Grand Canyon can be conducted. An integrated database is critical for *defining* and *delimiting* native fish populations, e.g., what is the relationship between mainstem and LCR HBC populations? This dataset is unique in that it represents one of the largest, most complete mark-recapture datasets on freshwater fish that spans 5 or more years. Besides providing retrospective analyses of population trends in relation to environmental changes, studies based on integrated datasets can provide profound understanding of distribution, movement, growth, recruitment, age structure, and health

of Grand Canyon native fishes. GCES Phase II contractors in possession of major fish databases include AGFD, Arizona State University, University of Arizona, BioWest, Hualapai Tribe/SWCA, and FWS.

## 2. Conduct a population analysis on Grand Canyon HBC.

Existing HBC catch data from GCES Phase II studies should be pooled and analyzed to further investigate the possible decline in the adult humpback chub population in Grand Canyon. One objective of the analysis should be to determine whether sampling conducted during GCES Phase II affected survivorship. This analysis should be conducted as soon as possible and results be made available to resource managers so that corrective actions can be formulated and further studies can be implemented.

Bio/West and ASU conducted separate analyses of Grand Canyon humpback chub populations using their respective datasets (mainstem and LCR, respectively; Valdez and Ryel 1995, Douglas and Marsh 1996a, 1996b). An accurate assessment of native fish populations is hampered by a lack of integration of catch data from GCES Phase II and precludes the development of accurate population models (Valdez and Ryel 1995). In light of an apparent population decline in HBC in Grand Canyon, there is an urgent need to conduct a population analysis using pooled GCES phase II capture records for native fishes. Populations analyses for other native fishes using pooled capture data is also critical; Weiss' (1993) analysis of the Grand Canyon flannelmouth sucker suggests this species has been in decline since the closure of Glen Canyon Dam.

## 3. Monitor native and non-native fish populations in Grand Canyon.

In addition to monitoring native and non-native fishes in the mainstem Colorado River, fish communities in tributaries should also be sampled on a routine basis. Tributaries are important to the Grand Canyon fish community because these environments provide spawning and rearing habitats for native mainstem fishes (HBC, flannelmouth sucker, bluehead sucker, speckled dace) as well as for common non-native fishes that use the mainstem (common carp, channel catfish, brown trout, rainbow trout, fathead minnow, plains killifish). Among the range of warm- and cool-water environments in tributaries, some have communities dominated by native fishes and some by non-native fishes. Thus, tributaries can serve as natural laboratories for assessing native/non-native interactions under warm- and cool-water conditions. Understanding the influence of temperature and flow regime on fish community composition is useful for predicting the effect of changes in future dam operations (e.g., flow and temperature modifications).

Because the largest reproducing population of endangered HBC resides in the LCR, regular seasonal sampling should be conducted in the lower 14 km to determine population status, reproduction, and recruitment of new cohorts. Data from monitoring continues the baseline of data established in GCES Phase II and allows evaluation of population trends in response to climatic and hydrologic trends and dam operations. Tributaries that should be routinely monitored include: Paria, LCR, Bright Angel, Shinumo, Tapeats, Kanab, and Havasu.

#### 4. Conduct studies on non-native fishes.

There is need for greater understanding of the population dynamics, growth, diet, dispersal, and movement of non-native fishes in Grand Canyon. A lack of understanding of the ecology of non-native fishes will hinder the development of successful management actions intended to benefit native fishes. Ideally, studies of non-native fishes should be integrated into studies of native/non-native fish communities. Studies on non-native fishes should complement and improve understanding of non-native/native fish interactions and success of control measures for non-native predators

#### 5. Geochemical, hydrology, climatology studies in the LCR.

Although the LCR has the largest known reproducing population of humpback chub, there is no historical perspective for the present situation. The presence of humpback chub in the LCR is dependent on maintaining the flow and water chemistry peculiar to that stream. With ever-increasing human pressure on water resources in the region, the long-term prospectus for maintaining the current supply of water for the lower LCR is not good.

The travertine deposits in the LCR provide information about past watershed conditions, hydrology, geochemistry, and climatology. Historical geochemistry may show that flow conditions and water quality may have allowed humpback chub to occupy areas much further upstream than present. An understanding of the past climatic and hydrologic environments is invaluable in predicting future impacts of ongoing trends, such as declining output of Blue Springs, the source of perennial base flow in the LCR. By establishing a baseline of past conditions in the LCR, studies of historical geochemistry can delimit the range of allowable environmental conditions for HBC and provide targets or standards for future ecosystem management efforts for the LCR.

Northern Arizona University researchers and the Flagstaff FRO conducted limited investigations on the distribution of HBC in the LCR in relation to geochemical conditions. Continuation of these studies is needed to identify geochemical characteristics of the LCR that allow HBC and other native fishes to be so successful in this stream. Geochemical studies can potentially reveal past geochemical and flow conditions in the LCR and detect whether the system has been degrading in recent times. Such studies can provide a baseline of minimum flow and water quality conditions necessary to support a reproducing HBC population in the LCR. At the very least, a better understanding of the distribution of humpback chub in the lower 21 km of the LCR relative to water chemistry and habitat is needed. From this knowledge, predictions of the consequences of changes in the quantity and quality of discharge from springs in the lower 21 km can be made and minimum flow and water quality standards can be established to protect the LCR humpback chub population. Given that this population is the largest and apparently only reproducing population of HBC in the Grand Canyon region, protection of this population is critical to recovery and long-term persistence of the species.

## *RECOMMENDED MANAGEMENT AND CONSERVATION ACTIONS*

The following management and conservation actions are recommended to reduce the likelihood of population loss and extirpation of native fishes and increase opportunities for recovery of endangered HBC in Grand Canyon:

### 6. Initiate a genetic management program for endangered and native fishes.

The purpose of a genetic management program for humpback chub is to assess the genetic resources among discrete populations, cryopreserve germplasm as a hedge against loss of genetic diversity through population loss or extirpation, and to use the germplasm to produce genetically appropriate hatchery stocks should the need arise in recovery and management efforts.

Humpback chub, like many endangered species, has reduced and scattered populations throughout its distributional range. This situation poses a threat to maintenance of the former genetic diversity of the species and may impair the ability of the species to persist over time. The first step in implementing a genetic management plan for humpback chub is to describe the available diversity among populations and to bank germplasm as hedge against genetic losses. These two objectives can be accomplished simultaneously by a program of collection, cryopreservation, and storage of humpback chub sperm from all extant populations. Genetic analysis will allow identification of populations with unique genetic character; these populations would be given high priority for recovery efforts. By using cryopreserved sperm from individuals of known genetic make-up, we can establish or enhance populations that are in the greatest danger of extinction.

The largest population of HBC in Grand Canyon is found in the LCR, and much smaller aggregations are found downstream in Middle Granite Gorge, Pumpkin Springs, and in the vicinity of major tributaries downstream from the LCR (Bright Angel, Shinumo, Kanab, and Havasu creeks) (Valdez and Ryel 1995). These downstream populations probably have a high genetic identity with the LCR population but this has not been demonstrated. A population of HBC is also present 30 miles upstream from the LCR at South Canyon and this population may not show a high level of genetic identity as no upstream movement of HBC this distance from the LCR has been observed (Valdez and Ryel 1995). The South Canyon population apparently spawns around warm springs in summer months, a life history trait that may reflect adaptation to the pre-dam mainstem habitat which contrasts with spring spawning in LCR HBC populations (Valdez and Ryel 1995). Genetic inventory of existing populations of HBC in Grand Canyon can be easily accomplished along with gene banking of sperm samples.

The Service started a genetic management program for endangered fishes in the upper Colorado River basin through the Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River Basin. Principal species include Colorado squawfish and razorback sucker. These efforts would be greatly enhanced by an integrated Service-wide program of basin-wide genetic management for bonytail chub, humpback chub, Colorado squawfish, and razorback sucker.

FWS should initiate a genetic management program to bank genetic resources of the endangered humpback chub in Grand Canyon. Sampled populations should include those from LCR, South Canyon, Middle Granite Gorge, Pumpkin Springs, and Bright Angel, Shinumo, Kanab, and Havasu creek reaches. Genetic resources for these populations will be protected by collection and cryopreservation of sperm employing methodologies already developed and refined by the Service. Banked sperm can be used to conduct genetic inventories of HBC populations as outlined in recommended research above, and can serve to augment the genetic diversity of captive brood stocks and production of genetically appropriate fish for stocking purposes. For most of the existing populations/aggregations, banking of sperm samples is the only way to protect population genetic resources against loss arising from population declines or extirpation.

#### 7. Establish a captive brood stock of endangered humpback chub.

FWS should re-establish a captive breeding stock of Grand Canyon HBC as a protective measure against future loss and to provide stocks of fish for research purposes, such as temperature and growth studies outlined in Part III, section 4. This conservation action is one of 7 conservation measures developed jointly by BOR, FWS, AGFD, NPS, and Navajo Nation Natural Heritage Program in 1990 (USBR 1990, USFWS 1990) and is yet to be successfully implemented.

#### 8. Management and control of large predatory exotic fishes.

A program to control large predatory exotics should be implemented. Brown trout have become more abundant in recent years in mainstem habitats in Grand Canyon and may be dependent on cooler tributaries (especially Bright Angel and Tapeats creeks) for reproduction. Populations of brown trout may be reduced by increasing fishing pressure on this species in the mainstem and tributaries. Large channel catfish are relatively abundant in the LCR, where they reproduce successfully and prey on humpback chub (Douglas and Marsh 1996b). Catfish populations may be reduced by periodic removal efforts focused on the lower 1 km of the LCR.

#### 9. Management of tributaries for native fishes.

Exotic trouts (rainbow and brown) are common in Bright Angel, Shinumo, and Tapeats creeks. The abundance of exotic trout in these streams may be detrimental to native fishes. However, little is known about the trout populations in the tributaries or of their impact on native fishes. Field studies on exotic trout in these streams should be implemented to better understand their ecology and provide knowledge critical to their management. Where appropriate, trout populations in the tributaries should be managed to minimize their impacts on native fishes. For example, increased angling of trout in Bright Angel and Shinumo creeks may reduce impacts of exotics on native fishes. However, Tapeats Creek appears to be too cold for most native fishes and has perhaps the best trout fishery of all the tributaries; this fishery appears to be relatively unexploited.

#### 10. Protection of key tributary confluences for native fishes.

Tributary confluences should be protected from excessive human impact during spawning and early life history stages for native fishes. GCES II investigators have collected adult and YOY HBC and other native fishes in the confluences of Paria, LCR, Bright Angel, Shinumo, Kanab and Havasu creeks. The LCR confluence supports the largest population of humpback chub and serves as a staging area and possibly a spawning area. At present the tributary confluences provide some of the most productive (and warm) habitat for native fishes of the Grand Canyon. Therefore, management strategies to enhance or stabilize native fish populations in the Grand Canyon must include tributary confluences. Some of these tributaries (in particular the LCR, Bright Angel, Shinumo, and Havasu) are heavily impacted by human activities during summer months and include destruction of benthic communities, building dams, and disposal of human wastes. At present we do not know the long-term effects of perturbation of these environments on native fishes. Confluences of the mentioned streams should be protected from undue disturbance during spring and summer months to minimize impacts on spawning and rearing life history stages of native fishes. As an interim measure, the lower 500 m of the LCR and the lower 200 m of other tributaries should be protected during the period of February-July. This period encompasses the spawning season and early life history stages of native fishes. At other times of the year the amount of traffic and activities of tourists should be controlled to minimize impacts.

#### 11. Establish an additional reproducing population of humpback chub in Grand Canyon.

At present, the LCR HBC population is the only reproducing population in Grand Canyon, and as discussed previously, is vulnerable to loss. Establishment of an additional population of humpback chub would reduce the likelihood of extirpation of the species in Grand Canyon. Re-establishment of a reproducing population of HBC in the mainstem is the ideal solution, but that action is neither certain nor expected in the near future. Thus, establishing an additional population in an appropriate tributary should be considered a critical first step in resolving the imperiled status of humpback chub in Grand Canyon.

Flagstaff FRO studies showed that Havasu Creek has array of habitat that is very comparable to that in the LCR, the model stream for humpback chub habitat (Gorman 1994). The HBC management team recommended in Part III, section 14, should investigate the feasibility of establishing a population of HBC in the lower 5 km of Havasu Creek. Because of the uncertainty of establishing humpback chub in Havasu Creek, this management action should not be viewed as resolving the imperiled status of the species in the mainstem Colorado River.

## **V. The ADAPTIVE MANAGEMENT PROCESS and RECOVERY of LISTED SPECIES**

Ecosystem/habitat restoration is usually viewed as necessary to effect recovery of endangered species. Species recovery is achieved when ecosystems are sufficiently restored to allow populations of listed species to be self-sustaining, viable components of biological communities. Thus, recovery of listed species signals the restoration of ecosystem health and function. Ideally, recovery of HBC in the context of Grand Canyon will occur when the environment of the Colorado River is sufficiently restored to a natural condition to allow the re-establishment of a viable reproducing mainstem population. The long-term goal of the AMP should be recovery of humpback chub in Grand Canyon, but the immediate goal is removal of jeopardy, which can be achieved by implementing the RPA. Ultimate responsibility for implementing the RPA and removal of jeopardy rests with the BOR, but the AMP can assist the BOR in its efforts.

The natural environment of the native fishes of Grand Canyon has been greatly altered by impounding the Colorado River at Glen Canyon and the introduction of non-native species of plants, fish, etc. For the first 30 years or so Glen Canyon Dam was operated for water storage, water delivery, and to maximize revenues from power generation without consideration of negative impacts on the environment. The cost of these impacts has been loss or degradation of habitat for native fishes, loss of native fishes, loss of stored sediments and beaches, and loss of natural function and character of the Colorado River (Clarkson et al. 1994). The Grand Canyon Protection Act of 1992 attempts to address the imbalance of assessing impacts of dam operations on the environment cost-free. In order to mitigate the negative impact of dam operations on Grand Canyon natural resources and its native fishes, dam operations must be modified sufficiently to allow restoration of the Colorado River ecosystem and maintenance of the native fish community. It should be realized that necessary changes in dam operations cannot be accomplished without assessing some cost on the economic component of dam operations. The AMP is the vehicle prescribed in the Glen Canyon Dam EIS and the Grand Canyon Protection Act that will seek ways to optimize dam operations between two competing goals: maximizing economic value of dam operations vs. ecosystem restoration and removal of jeopardy and maintenance of endangered and native fishes of Grand Canyon.

The Colorado River environment can be manipulated in two ways that may benefit native fishes: flow regime and temperature. The present flow regime is characterized by daily fluctuations in flow that alternately inundate and dewater edge and backwater habitats (AGFD 1996). Unstable water levels in backwaters and along river margins prevent the development of macrophytes, aufwuchs and the accompanying invertebrate communities that provide food resources for fish. Temperatures are cold, well below optimum levels for warmwater native fishes (Bulkley et al. 1982), thus preventing successful reproduction and retarding growth and survivorship of subadult life history stages (Hamman 1982, Marsh 1985, Lupher and Clarkson 1994, Valdez and Ryel 1995). Under a seasonally adjusted steady flow regime, it is possible that semi-isolated backwaters may be stable enough to allow sufficient solar warming to reach optimal temperatures (Hoffnagle 1996). However, the number and area of semi-isolated backwaters with the potential for sufficient warming over

extended periods may be relatively small. Implementation of a regime of low stabilized flows coupled with release of warmer water from Glen Canyon Dam has the greatest potential of increasing the number and area of stable, productive backwater and marginal habitats that are beneficial to native fish. The intent of the program of experimental flows outlined in the Biological Opinion is to test the impacts of steady high flows in the spring and low steady flows in the summer and fall on the aquatic environment of Grand Canyon.

With the establishment of the AMP, the environment of Grand Canyon will be actively managed by modifying dam operations, executing management and conservation actions, and conducting monitoring and research in an ongoing interactive learning process for the benefit of all natural resources, but especially for endangered fishes. There is a great need for additional knowledge to optimally manage flow and temperature in the mainstem Colorado River for the benefit of native and endangered fishes. A vigorous research program to address specific information needs must be executed in an orderly way to provide information in a logical sequence that allows efficient formulation of management plans. Monitoring needs to be conducted to detect environmental trends and assess the effects of management actions. Conservation actions need to be taken to safeguard natural resources. Information should be obtained and used in logical steps to minimize time required to implement management actions that will lead to recovery of humpback chub and protection of native fish populations in Grand Canyon.

The AMP/GCMRC could benefit by holding a meeting or forming a committee of expert scientists to review the recommendations presented in this report, review what information is available from GCES Phase II, review areas that need additional study, and prioritize monitoring and research activities for completion of information goals. The review group should set as its goal to implement the Biological Opinion RPA and develop actions that will lead to recovery of humpback chub in Grand Canyon. Involvement of expert scientists would provide continuity with past research and offer opportunities for achieving consensus in ways to conduct, coordinate and integrate future research and monitoring. Ideally, the review group would develop a roadmap and timetable with priorities for information acquisition, synthesis, and formulating management and recovery actions. The end-product of the group's effort should be an efficient, fully integrated monitoring, research and management program guided by ecosystem restoration and species recovery goals.

Recommended research, monitoring and management actions for the adaptive management process are summarized in Table 1. *Recommended actions* are divided into those that address the Biological Opinion RPA and RPM (Section III) and those that address the AMP (Section IV). *Relative applicability* assigned to the recommended actions reflects the level of relevance and priority for implementation. Relative applicability of actions are assessed for the GCMRC monitoring and research program, integration and synthesis of past GCES studies, and recovery of endangered fishes and removal of jeopardy. Actions with high overall applicability are needed to complete integration/synthesis of the present information base (e.g., mainstem habitat studies, integration of GCES Phase II fish databases, population analyses of native fishes), to develop a conceptual model of the Grand Canyon ecosystem, and to implement the Biological Opinion RPA (e.g., design and implement a program of experimental flows, including temperature studies on native and listed

fishes). Also, there is an urgent need to maintain the present information base through continued monitoring (e.g., monitor native and non-native fishes in mainstem Colorado River and key tributaries and their confluences). Finally, management and conservation actions need to be implemented (e.g., establish additional spawning populations of HBC, initiate a genetic management plan for HBC, establish captive broodstock for HBC). Recommended actions of moderate overall applicability can effectively be implemented in conjunction with ongoing monitoring and data integration (e.g., LCR studies), after there is sufficient integration and synthesis of GCES Phase II studies (e.g., develop razorback sucker management plan), during future experimental flows (e.g., protection of key tributaries), or when funds are available for implementation (e.g., predator control programs).

**TABLE 1. SUMMARY of RESEARCH , MONITORING, and MANAGEMENT RECOMMENDATIONS**

*Recommended Actions* refer to actions outlined in sections III and IV of this report. Numbers in parentheses refer to action numbers in sections III and IV. *Relative applicability* refers to relevance to implementation to research/monitoring, integration/synthesis, or recovery/management of endangered fishes: 1- high, 2- moderate, and dash indicates no applicability. *Research/monitoring* refers to GCMRC research and monitoring program. *Integration/synthesis* refers to completion GCES Phase II studies, databases, and analyses. *Recovery/management* refers to implementing the Biological Opinion RPA and RPM (removal of jeopardy) and providing opportunities for recovery of endangered fishes. The *overall* column shows the overall applicability of the recommended actions to the AMP.

Recommended Actions	Relative Applicability			
	research/ monitoring	integration/ synthesis	recovery / management	overall
<u>III. Address Biological Opinion Elements (RPA, RPM)</u>				
<i>Research and monitoring</i>				
experimental flow and thermal warming studies (1i, ii; 15)	1	2	1	1
native and non-native interactions (1iii; 7)	1	1	2	1
mainstem habitat studies (2i, ii; 1iv, v)	1	1	1	1
study and monitoring of food resources tied to native fishes (3; 7; 1vi)	1	1	2	1
temperature and growth studies on native fishes (4; 1i,ii)	1	2	1	1
study of fish diseases; establish baseline (5; 1vii)	2	1	1	1
native fish studies in mainstem (6; 15)	1	1	2	1
native fish studies in tributaries (7; 1v)	1	1	2	1
hydrologic/geochemical monitoring in tributaries (7; 1v)	1	1	2	1
LCR studies: food base and diet for native fishes (8; 3; 7)	1	1	2	1
LCR studies: HBC spawning (9; 7)	2	1	2	2
LCR studies: HBC growth and recruitment (10; 1i,ii; 4; 7)	1	1	2	1
LCR studies: HBC early life history studies (11; 1i,ii; 4; 7)	2	1	2	2
LCR studies: non-native fish interactions (12; 1iii; 7)	2	1	2	2
<i>Management and conservation</i>				
develop razorback sucker management plan (13)	-	-	2	2
establish additional spawning HBC population (14)	-	-	1	1
<u>IV. Address Adaptive Management Program</u>				
<i>Research and monitoring</i>				
integration of GCES Phase II fish databases (1)	-	1	1	1
population analyses of native and endangered fishes (2)	-	1	1	1
monitoring and studies of native fishes in Grand Canyon (3)	1	1	1	1
monitoring and studies of non-native fishes (3, 4)	1	1	2	1
hydrologic/geochemical monitoring in LCR (5)	1	1	2	1
<i>Management and conservation</i>				
initiate a genetic management plan for HBC (6)	-	-	1	1
establish captive broodstock for HBC (7)	-	-	1	1
execute predator control program (8)	-	-	2	2
manage and protect key tributaries for native fishes (9, 10)	-	-	2	2
establish additional spawning HBC population (11)	-	-	1	1

## DEVELOPMENT OF A LIFE HISTORY MODEL AND MANAGEMENT PLAN FOR RECOVERY OF HUMPBAC CHUB IN GRAND CANYON

The suggested stages for the development of life history and community model and management plan for recovery of the endangered humpback chub in Grand Canyon within an adaptive management framework are presented below and summarized in Figure 1. The life history and community models should be developed as components of the conceptual model of the Grand Canyon ecosystem. Development and implementation of the management plan and conservation actions need to be integrated into the adaptive management process and function as a component in the master adaptive management plan for Grand Canyon. The adaptive management process is presented as occurring in distinct stages or steps, but with time these will begin to merge into a continuous, cyclic process.

### **Stage I. Information acquisition: research and monitoring**

Research and monitoring provides the information needed to formulate and evaluate management plans and conservation actions. Continued monitoring is needed to detect short- and long-term population trends in native and non-native fishes in response to changing flow regimes and other environmental conditions. Monitoring also provides feedback for assessing the success of the Adaptive Management Program actions and the effects of other environmental influences on natural resources. Information needs for the Adaptive Management Program from Sections III and IV of this report are summarized in Table 1. The first cycle of information acquisition actions in Stage I could conceivably be completed before the year 2000. Specific information needs from Table 1 that are addressed by research or monitoring are:

#### Research

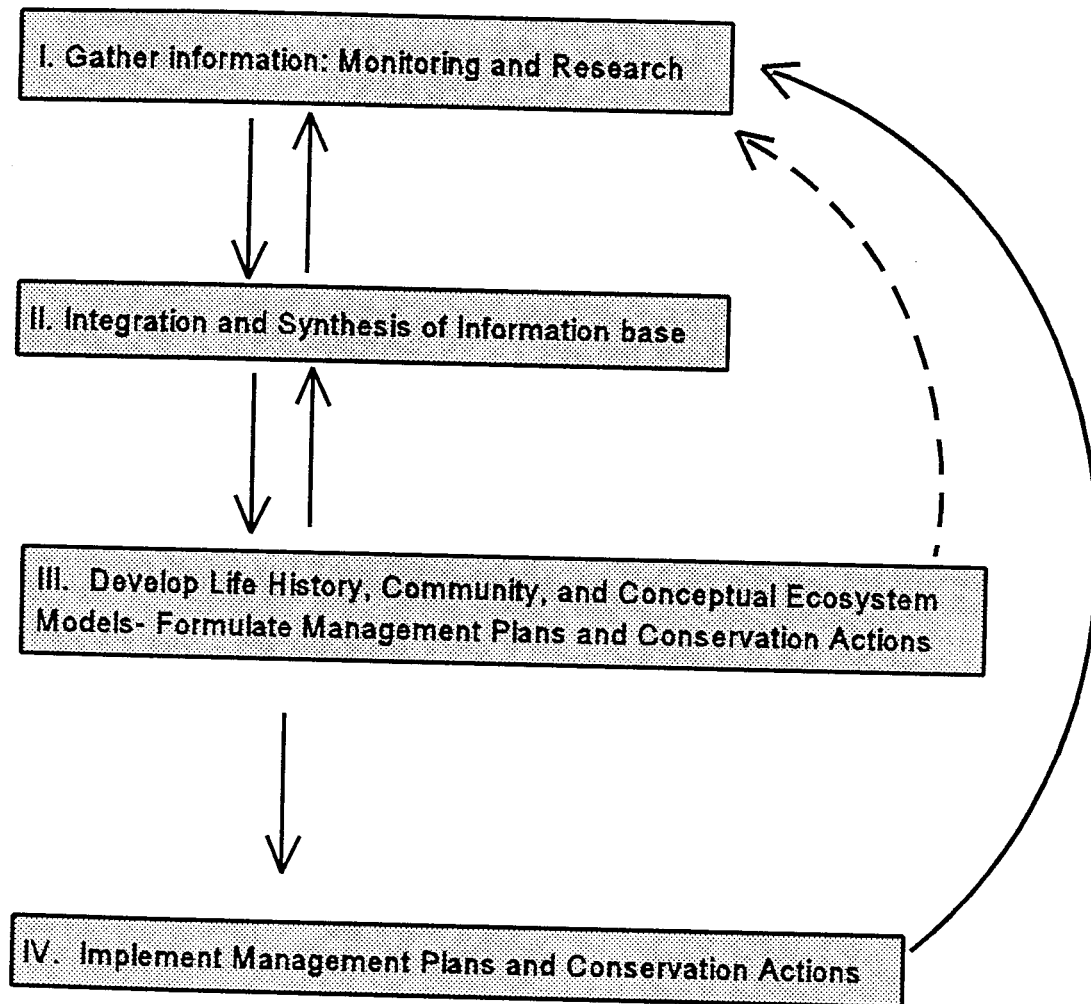
- Experimental flow and thermal warming studies (section III: 1i, ii; 15)
- Native and non-native interactions (section III: 1iii; 7)
- Mainstem habitat studies (section III: 1iv, v; 2i, ii)
- Food resources tied to native fishes (mainstem, LCR, other tributaries) (sec. III: 1vi; 3; 7; 8)
- Temperature and growth studies on native fishes (section III: 1i, ii; 4)

#### Monitoring

- Monitoring and studies of native and endangered fishes (sec. III: 1i, ii; 6; 7; 9; 10; 11; 15; IV: 3)
- Monitoring and studies of non-native fishes (sections III: 1iii; 7; 12; IV: 3; 4)
- Monitoring food base in mainstem and tributaries (sections III: 1vi; 3; 7; 8)
- Hydrologic/geochemical monitoring in LCR and other tributaries (sec. III: 1v; 7; IV: 5)
- Fish diseases (section III: 1vii; 5)

The above information needs have high applicability for implementation (Table 1). Some of this information can be derived from GCES Phase II databases through integration and synthesis (below), but some information, such as the experimental flow and thermal warming, temperature and growth, and mainstem habitat, require new research as data sources. Additional information needs addressed by new research are outlined in the next section, Stage II.

**Figure 1. Recovery of Humpback Chub in Grand Canyon  
Within an Adaptive Management Framework**



## **Stage II. Integration and synthesis of information base.**

The first cycle of Stage II integration/synthesis actions should be completed before the year 2000.

### **A. Integration/synthesis.**

Integration and synthesis of the existing GCES Phase II information base is the first step in understanding the status of native and endangered fish populations in Grand Canyon. Actions with high overall applicability from Table 1 requiring further integration and synthesis include:

- Integration of GCES Phase II fish databases (section IV: 1)
- Population analyses of native and endangered fishes (section IV: 2; see B. below)
- Mainstem habitat studies (sections III: 1iv, v; 2i, ii)
- Monitoring and studies of native and endangered fishes (sec. III: 1i, ii, 6; 7; 9; 10; 11; 15; IV: 3)
- Monitoring and studies of native/non-native fishes (sec. III: 1iii; 7; 12; IV: 3; 4)
- Monitoring food base in mainstem and tributaries (sections III: 1vi, 3; 7; 8)
- Hydrologic/geochemical monitoring in LCR and other tributaries (sec. III: 1v; 7; IV: 5)
- Establish baseline database for fish diseases (sections III: 1vii; 5)

### **B. Population analyses: status and trends.** (Section IV: 2)

Population analyses of humpback chub and other native fishes are the first priority product of the integration/synthesis stage. The coupling of existing databases with ongoing monitoring will allow retrospective/prospective analyses of population status and trends. These studies will be possible only when GCES Phase II fish capture data are fully pooled and integrated.

Information needs from analyses:

- Population analysis: age and size structure, seasonal and long-term trends in population size/age/composition/condition factor.
- Survivorship and life table characteristics (if possible).
- Relationship between population trends and environmental trends.
- Movement and relationship of mainstem and LCR HBC population components.
- Movement of other native fishes between mainstem and tributaries.
- Develop predictive population models for HBC and other native fishes of Grand Canyon that can account for environmental trends and management actions.

C. Physiological and ecological requirements for spawning and rearing HBC.  
( Section III: 1i, ii; 4; 9; 10; 11; 15)

Physiological and ecological requirements for spawning, rearing, survivorship of humpback chub need to be determined from analysis of existing and new sources of data. This information is needed in advance of research to determine the ability of Colorado River ecosystem to deliver required conditions (D., below).

Information needs (acquired through Stage I, Research and Monitoring):

Physiological requirements for spawning of humpback chub: minimum temperature regimes for maturation of oocytes, fertilization, embryogenesis, hatching.

Ecological conditions associated with spawning humpback chub: habitat, food, population characteristics, hydrological ques, physical factors.

Physiological conditions for rearing of larval and young-of-year humpback chub: temperature and flow regimes for optimal growth to assure recruitment of young.

Ecological conditions for rearing of larval and young-of-year humpback chub: habitat, food, biological factors (competition, predation), physical factors.

D. Determine possible environmental conditions in mainstem habitats for reproduction of HBC.  
(Section III: 1; 2; 15)

Physical and ecological conditions that will allow successful spawning and recruitment of humpback chub in the mainstem Colorado River need to be determined from existing or new sources of data. There is a need to know whether flow and temperature conditions in the mainstem can be sufficiently modified by dam operations to allow establishment of reproducing populations of HBC. Assessment of possible conditions are based on comparison with studies conducted in the LCR, e.g., habitat studies (C., above). Determination of environmental conditions in mainstem habitats need to be conducted during seasonally adjusted experimental flows.

Information needs (acquired through Stage I, Research and Monitoring):

Availability of HBC spawning and rearing habitat in the Colorado River: abundance and distribution relative to requirements for spawning, stability, temperature regime.

Experimental flows and temperature modification: what flow characteristics and temperatures provide conditions for suitable spawning habitat and rearing of young?

***Stage III. Develop life history, community, and ecosystem models and formulate management plans and conservation actions.***

Stage II integration/synthesis of information from Stage I research and monitoring efforts will identify the physiological and ecological requirements for spawning and recruitment of HBC and reveal the potential for the Colorado River and tributaries to provide suitable conditions for establishing spawning populations. In Stage III, initial life history models for HBC and other native and non-native fishes in Grand Canyon can be formulated. Ideally, the initial life history models should be integrated into a community model and then tied to a larger conceptual model of the Grand Canyon ecosystem in order to identify links with other biological and physical components and common elements for ecosystem management. From this model building process, management plans and conservation actions can be formulated and additional areas for research and refinements in monitoring can be identified. The first cycle of Stage III actions should commence as soon as information is available from Stages I and II, ideally by the year 2000.

***Stage IV. Implement and refine management plans and conservation actions.***

Management recommendations and plans for needed flow and temperature modification to allow re-establishment of a spawning population of HBC (and perhaps razorback sucker) in Grand Canyon will be derived from the initial life history, community, and conceptual ecosystem models (Stage III). Implementation of initial management plans should address jeopardy and recovery of HBC in Grand Canyon and should be integrated into a master management plan for Grand Canyon natural resources. With successive cycles, the management plan is expected to undergo continual refinement based on new information (iteration of Stages I-IV) and the response of HBC to management and conservation actions (as detected through the monitoring program). The first cycle of Stage IV actions can be implemented as soon as management plans are formulated (in part or in whole). Conceivably, some management actions could be implemented by the year 2000.

**Implement conservation actions to guard against losses for endangered fishes.**

(Sections III: 14; IV: 6; 7; 11).

As a corollary to the ecosystem management plan, conservation actions need to be implemented to safeguard critical habitat and population resources from further losses and improve opportunities for future recovery of HBC ( and perhaps razorback sucker) in Grand Canyon. Conservation actions need to be implemented early (prior to year 2000) in the adaptive management process because benefits for endangered fishes of Grand Canyon may take some time to appear (e.g., re-establishing a mainstem HBC population). Recommended conservation actions include:

- Establish an additional reproducing population of HBC in one of the Grand Canyon tributaries.
- Establish captive broodstocks and gene banks representative of Grand Canyon HBC populations.
- Develop a genetic management plan for Grand Canyon HBC.
- Develop a management plan for maintenance of razorback sucker in Grand Canyon.

## CITED LITERATURE AND REPORTS

- Allan, N. L. 1993. Distribution and abundance of fishes in Shinumo Creek in Grand Canyon. Unpubl. Master's thesis, University of Arizona, Tucson. 76 p.
- Arizona Game and Fish Department (AGFD). 1996. Ecology of Grand Canyon Backwaters. Report submitted to U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, Arizona. Arizona Game and Fish Department, Phoenix, Arizona.
- Brouder, M.J. and T.L. Hoffnagle. 1997. Distribution and prevalence of the Asian fish tapeworm, *Bothriocephalus acheilognathi*, in the Colorado River and tributaries, Grand Canyon, Arizona, including two new host records. J. Helminthol. Soc. Wash. 64:219-226.
- Bulkley, R.V., C.R. Berry, R. Pimentel and T. Black. 1982. Tolerance and preferences of Colorado River endangered fishes to selected habitat parameters. Pages 185-241 in Miller, W.H., J.J. Valentine, D.L. Archer, H.M. Tyus, R.A. Valdez and L.R. Kaeding, ed. Part 2, Colorado River Fishery Project Final Report Field Investigations. Report to U.S. Bureau of Reclamation, Salt Lake City Utah. U.S. Fish and Wildlife Service, Salt Lake City, Utah.
- Clarkson, R. W., O.T. Gorman, D.M. Kubly, P.C. Marsh, and R.A. Valdez. 1994. Management of discharge, temperature, and sediment in Grand Canyon for native fishes. Proc. Desert Fishes Council. Vol. XXV:20-21. Also available as unpubl. manuscript from authors.
- Clarkson, R.W., A.T. Robinson, and T.L. Hoffnagle. 1997. Asian tapeworm (*Bothriocephalus acheilognathi*) in native fishes from the Little Colorado River, Grand Canyon, Arizona. Great Basin Naturalist: 57:66-69.
- Douglas, M.E. and P.C. Marsh. 1996. Population estimates/population movements of *Gila cypha*, an endangered cyprinid fish in the Grand Canyon region of Arizona. Copeia 1996:15-28.
- Douglas, M.E. and P.C. Marsh. 1996. Final Report: Ecology and conservation biology of humpback chub (*Gila cypha*) in the Little Colorado River. Submitted to U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff Arizona. Department of Zoology and Museum and Center for Environmental Studies, Arizona State University, Tempe, Arizona.
- Gorman, O.T. 1988. The dynamics of habitat use in a guild of Ozark minnows. Ecol. Monogr. 58:1-18.
- Gorman, O.T. 1994. Glen Canyon Environmental Studies Phase II Final Report. Habitat use by humpback chub, *Gila cypha*, in the Little Colorado River and other tributaries of the Colorado River. Submitted to U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, Arizona. U.S. Fish and Wildlife Service, Arizona Fishery Resources Office, Flagstaff, Arizona. 303 p.

- Gorman, O.T. 1994. Draft trip report on Lake Mohave razorback sucker sperm cryopreservation pilot project. Misc. Technical Report, U.S. Fish and Wildlife Service, Arizona Fisheries Resources Office, Flagstaff, Arizona. 5p.
- Gorman, O.T. 1996. Lake Mohave razorback sucker monitoring studies: operations at Willow Beach NFH, March 1996. Draft Report. Misc. Technical Report, U.S. Fish and Wildlife Service, Arizona Fisheries Resources Office, Flagstaff, Arizona. 8p.
- Gorman, O.T., S.C. Leon and O.E. Maughan. 1993. Glen Canyon Environmental Studies Phase II Annual Report, 1992. Habitat use by humpback chub, *Gila cypha*, in the Little Colorado River and other tributaries of the Colorado River. Submitted to U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, Arizona. U.S. Fish and Wildlife Service, Arizona Fishery Resources Office, Flagstaff, Arizona. 34 p.
- Gorman, O.T. and D.M. Stone. 1997. Ecology of spawning humpback chub, *Gila cypha*, in the Little Colorado River near Grand Canyon, Arizona. Environmental Biology of Fishes: *in press*.
- Gorman, O.T. and T. R. Tiersch. 1996. Protocols for field collection of sperm from fish. Misc. Technical Report, U.S. Fish and Wildlife Service, Arizona Fisheries Resources Office, Flagstaff, Arizona. 5p.
- Gorman, O.T., T.R. Tiersch, J.H. Williamson, G.J. Carmichael. 1996. Cryopreservation of germplasm in the endangered razorback sucker and humpback chub: 1995 field studies. Proc. ASIH 1996 Annual Meeting, p 156; Proc. XXVII Annual Symp. Desert Fishes Council.
- Hamman, R.L. 1982. Spawning and culture of humpback chub. Prog. Fish-Cult. 44:213-216.
- Hoffnagle, T. L. 1996. Changes in water temperature of backwaters during fluctuating vs. short-term steady flows in the Colorado River, Grand Canyon. Pages 128-141 in Ecology of Grand Canyon Backwaters. Report to U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, Arizona. Arizona Game and Fish Department, Phoenix.
- Kaeding, L. R. and M. A. Zimmerman. 1982. Life history and population ecology of the humpback chub in the Little Colorado and Colorado Rivers of Grand Canyon, Arizona. Pages 281-320 in Miller, W.H., J.J. Valentine, D.L. Archer, H.M. Tyus, R.A. Valdez and L.R. Kaeding, ed. Part 2, Colorado River Fishery Project Final Report Field Investigations. Report to U.S. Bureau of Reclamation, Salt Lake City Utah. U.S. Fish and Wildlife Service, Salt Lake City, Utah.
- Kaeding, L.R. and M.A. Zimmerman. 1983. Life history and ecology of the humpback chub in the Little Colorado River and Colorado rivers of the Grand Canyon. Trans. Amer. Fish. Soc. 112:577-594.

- Lupher, M. L. and R. W. Clarkson. 1994. Temperature tolerance of humpback chub (Gila cypha) and Colorado squawfish (Ptychocheilus lucius) with a description of culture methods for humpback chub. *In* Glen Canyon Environmental Studies Phase II 1993 Annual Report submitted to U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, Arizona. Arizona Game and Fish Department, Phoenix.
- Marsh, P.C. 1985. Effect of incubation temperature on survival of embryos of native Colorado River fishes. *Southwest. Nat.* 30:129-140.
- Mattes, W. P. 1993. An evaluation of habitat conditions and species composition above, in, and below Atomizer Falls complex in the Little Colorado River. Master's thesis, School of Renewable Natural Resources, University of Arizona, Tucson, Arizona.
- Meretsky, V.J. O.T. Gorman, M.E. Douglas, P.C. Marsh, and R.A. Valdez. 1996. Condition of humpback chub in the Colorado River basin: seasonal, geographic, and long-term trends. Manuscript in prep; draft available from senior author.
- Mc Guinn-Robbins, D. K. 1995. Comparison of the number and area of backwaters associated with the Colorado River in Glen, Marble and Grand Canyons, Arizona. Draft Report: April 1995. Submitted to U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, Arizona. Arizona Game and Fish Department, Phoenix, Arizona
- Minckley, C. O. 1990. Final Report on research conducted on the Little Colorado River population of the humpback chub, during April-May, 1990. Submitted to Arizona Game and Fish Department, Phoenix.
- Minckley, C. O. 1996. Observations on the biology of the humpback chub in the Colorado River basin 1908-1990. PhD. thesis, Northern Arizona University, Flagstaff *and* Final Report submitted to Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, Arizona. Contract No. 1FC-40-10500. 203p.
- Minckley, W.L., P.C. Marsh, J.E. Brooks, J.E. Johnson and B.L. Jensen. 1991. Management toward recovery of the razorback sucker. Pages 301-357 *in* W.L. Minckley and J.E. Deacon, ed. *Battle against extinction: native fish management in the American west*. Univ. Arizona Press, Tucson.
- Otis, E. O. 1994. Distribution, abundance, and composition of fishes in Bright Angel and Kanab Creeks, Grand Canyon National Park, Arizona. Unpubl. Master's thesis, University of Arizona, Tucson. 196p.
- Otis, E. O., and E. O. Maughan. 1994. Aquatic habitat availability in Bright Angel, Tapeats, Deer, and Kanab creeks, Grand Canyon National Park, Arizona. Unpubl. Final Report submitted to U.S. Fish and Wildlife Service, Arizona Fisheries Resources Office, Pinetop. 76 p.

- Robinson, A. T., R.W. Clarkson, R.E. Forrest. 1996. Spatio-temporal distribution, habitat use, and drift of early life stage native fishes in the Little Colorado River, Grand Canyon, Arizona, 1991-1994. Final Report: February 23, 1996. Submitted to U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff Arizona. Arizona Game and Fish Department, Phoenix, Arizona.
- Robinson, A.T., D.M. Kubly, and R.W. Clarkson. 1995. Limnological factors limiting the distributions of native fishes in the Little Colorado River, Grand Canyon, Arizona. Draft Final Report: May 1995. Submitted to U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff Arizona. Arizona Game and Fish Department, Phoenix, Arizona.
- Robinson, A.T. 1995. Monitoring of humpback chub and sympatric native fish populations in the Little Colorado River, Grand Canyon, Arizona; 1991-1994. Draft Final Report: April 1995. Submitted to U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff Arizona. Arizona Game and Fish Department, Phoenix, Arizona.
- Strength, D. A. 1997. Travertine deposition in the Little Colorado River, Arizona and habitat for the endangered humpback chub. Unpubl. Masters thesis, Northern Arizona University, Flagstaff.
- Tyus, H.M. 1992. An instream flow philosophy of recovering endangered Colorado River fishes. *Rivers* 3(1):27-36.
- U.S. Bureau of Reclamation (USBR). 1990. Glen Canyon Environmental Studies Phase II Draft Integrated Research Plan, Volume 2, August 1990. Glen Canyon Environmental Studies Program, 121 E. Birch St, Suite 307, Flagstaff, AZ 86001.
- U.S. Bureau of Reclamation (USBR). 1995. Operation of Glen Canyon Dam Final Environmental Impact Statement, March 1995. Bureau of Reclamation, 125 South State Street, Salt Lake City, UT 84138-1102.
- U.S. Fish and Wildlife Service (USFWS). 1978. Final Biological Opinion: Operation of Glen Canyon Dam. 2-21-93-F-167. December 21, 1994. Phoenix Ecological Services Office, Phoenix, Arizona. 56 pp.
- U.S. Fish and Wildlife Service (USFWS). 1987. Final Biological Opinion: Operation of Glen Canyon Dam 2-21-93-F-167. December 21, 1994. Phoenix Ecological Services Office, Phoenix, Arizona. 56 pp.
- U.S. Fish and Wildlife Service (USFWS). 1990. Operation of Glen Canyon Dam (BR-AZ) - section 7 consultation and related Environmental Impact Statement (EIS). Memorandum to Regional Director, Bureau of Reclamation, Salt Lake City. Acting Field Supervisor, Ecological Services, Phoenix, Arizona.

- U.S. Fish and Wildlife Service (USFWS). 1994. Final Biological Opinion: Operation of Glen Canyon Dam as the Modified Low Fluctuating Flow Alternative of the Final Environmental Impact Statement Operation of Glen Canyon Dam. 2-21-93-F-167. December 21, 1994. Phoenix Ecological Services Office, Phoenix, Arizona. 56 pp.
- U.S. Fish and Wildlife Service (USFWS). 1994. Operation of Glen Canyon Dam - Fish and Wildlife Coordination Act Report. June 28, 1994. Phoenix Ecological Services Office, Phoenix, Arizona. 106 pp.
- U.S. Fish and Wildlife Service (USFWS). 1995. Biological and Conference Opinions on Operation of Glen Canyon Dam - Controlled Release for Habitat and Beach Building. UC-320, ENV-1.00. February 16, 1996. Phoenix Ecological Services Office, Phoenix, Arizona. 42 pp.
- Valdez, R. A. and R. J. Ryel. 1995. Life history and ecology of the humpback (Gila cypha) in the Colorado River, Grand Canyon, Arizona. Final Report. Submitted to U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff Arizona. Bio/West Inc. 1063 West 1400 North, Logan, UT 84321
- Weiss, S. J. 1993. Population structure and movement of flannelmouth sucker in the Paria River. Unpubl. Master's Thesis, University of Arizona, Tucson. 130p.
- Wydoski, R.S. and J. Hamill. 1991. Evolution of a cooperative recovery program for endangered fishes of the upper Colorado River basin. Pages 123-135 in W.L. Minckley and J.E. Deacon, eds. Battle against extinction: Native fish management in the American West. University of Arizona Press, Tucson.